الجامعة البريطانية في دبي

The British University in Dubai

The Effect of Shading Devices on the Energy Consumption of Buildings: A Study on an Office Building in Dubai

تأثير وسائل التظليل على استهلاك الطاقة في المباني
دراسة تحليلية لمبنى تجاري (مكاتب) في دبي

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Research Project submitted in partial fulfillment of the requirements for the degree of MSc Sustainable Design of the Built Environment

Faculty of Engineering & IT

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بسم الله الرحمن الرحيم

الجامعة البريطانية في دبي

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Executive Summary

The world is witnessing a global movement working towards the goal of decreasing emissions that are causing the global warming phenomenon. The United Arab Emirates is striving to mitigate the effects of global warming by launching numerous initiatives that contribute to reducing emissions. One of the main sources of these emissions in the UAE is the buildings where the cooling loads required by buildings in Dubai accounts for 60% of the summer peak electricity load. Thus it is important to propose solutions to decrease energy consumptions of these buildings. Therefore, this study aims to quantify the potential energy savings achievable by external shading devices.

An extensive literature review was performed to highlight relevant information to incorporate into the design of this study. Energy consumption of an existing office building in Dubai was calculated by means of a computer energy simulation tool; the IES-VE software. The existing building was modeled and used as a base case. Four different types of shading devices were tested: horizontal overhangs, vertical side fins, horizontal louvers and vertical louvers. All these shading devices where applied in their most basic configuration where all the shading devices were not tilted at an angle but rather kept straight. The energy consumption simulated was carried out for both the summer (June) and winter (December) seasons to check variations. In addition, the shading devices were tested on the South, West and East facades. The North facade was excluded due to the fact that it is least exposed to direct solar radiation thus shading on that facade is not required.

The results of the simulation showed that the application of fixed external shading devices always decreased energy consumption for all different scenarios modeled thus is always beneficial. The simulation results showed that the horizontal louvers performed most effectively on all three facades where they achieved potential energy savings of 14.58%, 10.31% and 10.30% on the South, West and East facades respectively. All shading devices performed effectively on the South facade achieving potential energy savings of 10.54% by vertical louvers, followed by 7.89% by overhangs and 6.47% by vertical fins.

The louvers, both horizontal and vertical, were generally more effective than the horizontal overhangs and vertical side fins. This can be due to the lack of tilt in the shading devices. Thus this study shows that straight horizontal shading devices are more effective than straight vertical shading devices. It is expected that adding small tilts to these shading devices can result in higher energy savings as evident in previous studies.

Based on the results discussed above, it is concluded that horizontal louvers perform best on all tested orientations. The optimum scenario simulated is the application of horizontal louvers on all facades. The annual energy consumption of the optimal case is reduced to 65.60 MWh while the base case is 97.90 MWh. The energy savings achieved by employing this configuration is 33%.

In conclusion, the study provides evidence that prove that the employment of fixed external shading devices on all facades of a building can reduce energy consumption dramatically consequently increasing the overall energy performance of the building. Based on these findings, it is recommended that the incorporation of external shading devices is considered in early stages of the building design phases, especially for buildings that have high window to wall ratios, which are very common in Dubai. Also, it is important to note that shading design calculations should be done specifically to the latitudes and longitudes of Dubai to obtain accurate measurements of shading devices thus causing higher energy savings.

Keywords: shading devices, energy saving, computer simulation, UAE, Gulf region, hot climate

الملخص

يشهد العالم حركة عالمية تعمل من أجل تحقيق هدف خفض الانبعاثات التي تسبب ظاهرة الاحتباس الحراري. تسعى دولة الإمارات العربية المتحدة جاهدة للتخفيف من آثار الاحترار العالمي من خلال إطلاق العديد من المبادرات التي تسهم في الحد من الانبعاثات. احدى المصادر الرئيسية لهذه الانبعاثات في دولة الإمارات العربية المتحدة هي المباني حيث تبلغ ذروة طاقة التبريد اللازمة لهذه المباني في دبي نسبة 60% من الطاقة الكهربائية المستهلكة في الصيف . وبالتالي فإنه من المهم اقتراح حلول لخفض استهلاك الطاقة في هذه المباني. لذلك، تهدف هذه الدراسة إلى تقدير الطاقة الممكن توفيرها من خلال استعمال وسائل التظليل الخارجية .

وقد أنجزت دراسات مرجعية مكثفة لتسليط الضوء على المعلومات ذات الصلة التي يمكن أن تدرج في تصميم هذه الدراسة. فقد حسب استهلاك الطاقة في مبنى مشغول بمكاتب في دبي باستعمال محاكي للطاقة بواسطة برمجيات IES-VE .فقد نمذج المبني الموجود عن طريق البرنامج واستعمل حالة مرجعية . اختبرت أربعة أنواع من وسائل التظليل هي : وسائل تظليل ممتدة أفقياَو وسائل تظليل طولية، و كاسرات شمسية أفقية و كاسرات شمسية طولية. طبقت كل وسائل التظليل في تكوينها الاساسي بصورة مستقيمة ،و لم يتم امالتها بأي زاوية. تم إجراء محاكاة استهلاك الطاقة لفصلي الصيف (يونيو) والشتاء (ديسمبر) لاختبار الاختلافات بينهما.إضافة إلى ذلك ،فقد اختبرت أجهزة التظليل على واجهات الجنوب والغرب والشرق. وتم استبعاد الواجهة الشمالية لأنها الأقل تعرضاَ للإشعاع الشمسي المباشر وبالتالي لا تتطلب تظليلاً.

أظهرت نتائج المحاكاة أن تطبيق أجهزة التظليل الخارجية دائما تخفض استهلاك الطاقة لجميع حالات المبنى المدروسة، فهي دائما مفيدة. وقد بيّنت نتائج المحاكاة أن وسيلة الكاسرات الشمسية الأفقية كانت أكثر فعالية على كافة الواجهات الثلاث حيث كانت نسب الطاقة المحققة الممكن توفيرها في الثلاث حالات ,14.58% ، 10.31% ،و 10.30% في الجنوب، والغرب و الشرق على التتابع . وأظهرت نتائج المحاكاة أن وسائل التظليل كلها في الواجهة الجنوبية فعالة و كانت نسبة الطاقة المحققة الموفرة 10.54% عن طريق استخدام كاسرات شمسية طولية تليها 7.89% من وسائل التظليل الممتدة الأفقية ثم 6.47% من وسائل تظليل طولية .

كانت الكاسرات الشمسية الأفقية و الكاسرات الشمسية الطولية كليهما أكثر فعالية من وسائل التظليل الممتدة الأفقية و وسائل التظليل الطولية، و قد يكون هذا نتيجة القصور في إمكان إمالتها. و بالتالي هذه الدراسة توضح ان وسائل التظليل الافقية افضل من وسائل التظليل الطولية . و من المتوقع أن إضافة ميلان بسيط لوسائل التظليل قد يوفر طاقة اكثر، كما وضحت دراسات سابقة.

يستخلص من نتائج المناقشة السابقة أن وسائل التظليل الافقية أفضل الوسائل وفي جميع الاتجاهات.وأن التكوين الأمثل لمزيج من أجهزة التظليل على أن يكون التطبيق من الكاسرات الشمسية الأفقية على كل الواجهات . إذ كانت نسبة الطاقة المحاكاة الممكن توفيرها سنويا في هذه الحالة ,33% ، حيث تم تخفيض استهلاك الطاقة السنوي من 97.90 MWh الى 65.6 MWh
.

والخلاصة، تزودنا هذه الدراسة بأدلة تثبت أن توظيف وسائل التظليل الخارجية على جميع الواجهات لمبنى يمكن أن تقلل من استهلاك الطاقة بشكل كبير، وبالتالي زيادة أداء الطاقة الإجمالي للمبنى. واعتماداً على ما توصلنا إليه، نوصي بأخذ إدماج وسائل التظليل الخارجية في المراحل الأولى من مراحل تصميم المباني، وخاصة في المباني التي لها نوافذ عالية ، و هي كثيرة في دبي .و من المهم أن نلاحظ وجوب القيام بحسابات التصميم للتظليل وفق خطوط العرض وخطوط الطول في دبي تحديداً، بغية الحصول على قياسات دقيقة لأداء أجهزة التظليل مما يؤدي إلى ارتفاع في توفير الطاقة.

الكلمات الرئيسية : وسائل التظليل، الطاقة الموفرة، محاكاة الكمبيوتر، الإمارات العربية المتحدة، منطقة الخليج، مناخ حار

Dedication

To Laila Yassine, my eldest sister, in every sense of the word. Thank you for continuously inspiring me and making me believe in myself.

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1. Introduction

A building's facade is the main element on which a building's appeal is judged on, similar to how books are judged by their covers. One takes a look at a building and immediately judges its beauty based on his/her perceptions and experience. The form, shape, color and materials used determine whether the building is bulky, light, modern or boring. The aesthetic quality of a building also adds to the cultural and urban context of a city. For these reasons, it is commonly agreed upon that the aesthetics of the building envelope, especially main facades, are highly considered during the design process. Aside from its appearance, the building envelope's design is crucial as it is the main protective layer that shields the building and its occupants from the surrounding external factors, such as the climate and noise. The materials used in the envelope controls the transfer of light, sound and air that go into the building.

One of the most popular materials used for facades is glass, especially curtain walls, or 'glass boxes', a term framed by ASHRAE (2009). Glass is perceived as one of the most aesthetically pleasing materials that can be used for building facades. Its sleek appearance signifies transparency, modernism, minimalism and technology which go hand in hand with today's ideologies in general (Kim et al, 2007). It is used in famous towers all over the world, regardless of the local climate, such as Burj Khalifa in Dubai, and the Shanghai Tower in China.

Unfortunately, when it comes to sustainability, despite the commercial brainwashing efforts that claim that glass is a sustainable material, it is still debatable (Butera, 2005). The thermal properties of glass are not as pleasing as its aesthetic appearance. Although advancements in glass technologies have minimized the conduction of heat through glass walls, yet the fact that glass still conducts five times more solar heat than a well insulated wall remains true. A glass wall transmits 30-70% of solar radiation to the building's interior, while a solid wall transmits none (ASHRAE, 2009). Building fully glazed faced buildings in cold climate poses a risk of over heating during the summer, while having such building in hot climates dramatically increases cooling loads.

In the hot harsh climate of Dubai, it is important to control the amount of solar radiation that is transmitted to the building's interior. This heat affects the thermal and visual comfort of the occupants, especially those who are sitting close to external windows. It was found that having excess sunlight enter the building has negative effects on occupants' health where it can cause fatigue and insomnia, to name a few (Aboulnaga, 2005). It was also found that due to the thermal properties of glass, the temperature of the interior glass surfaces of fully glazed facades can be quite high even on cold but sunny days of the year, which increases temperature in the building causing discomfort of occupants (Bessoudo et al, 2010). On another note, allowing excess solar radiation will increase the temperature inside the building, which subsequently adds more load on the mechanical HVAC system to provide more cooling. This causes an increase in utility bills as well as CO2 emissions. Buildings in Dubai consume very high levels of energy due to the high cooling loads required which consume 40% of energy and have peaked at 60% (DEWA, 2010). In an attempt to assess current glazed buildings in Dubai, Aboulnaga (2005) looked at 15 buildings with 40-90% glazed areas in their facades. His study showed that glass was misused in 70% of the buildings. These buildings increased cooling loads substantially, and caused visual discomfort and glare (Aboulnaga, 2005). Thus it is important to propose solutions to decrease energy consumptions of these buildings. Despite this data, new buildings with fully glazed facades are still being built the most in Dubai, as it is obvious that Dubai is focused on building an international city based on prestige, regardless of the environmental impact these actions might cause (Bahaj et al, 2008). Surprisingly, different surveys conducted on an international level showed that architects usually do not consider thermal comfort or solar gains when designing windows, but rather cared about the appearance of the building (Menzies & Wherrett, 2005, Kim et al, 2007). Considering those two elements should be done by multi-disciplinary professionals- architects, HVAC engineers- but it rarely happens (Menzies & Wherrett, 2005).

To balance between glass's aesthetic appeal, and their transmittance of high solar radiation levels, shading can be integrated in the design; internal and external as well as fixed and movable. Internal shading elements are less efficient in terms of thermal gains as they block the solar radiation after they have passed through the building envelope and entered the building. Thus, internal shading is more effective in controlling the light that enters the building, but not solar radiation (Givoni, 1994). External shading proved to be the most effective type of shading since it is best to block the solar radiation as close to possible to its source (Offiong & Ukpoho, 2004, Kim et al, 2012). External shading device can give up to 11% energy savings (Kim et al, 2012). Although shading can serve as an excellent mean to mitigate heat gain into buildings, it is usually used to give stylistic impressions, similar to poor designs of windows (Butera, 2005).

Numerous researches investigated various glass technologies and their effectiveness in blocking solar radiation. However, very little was found on the shading of glass facades. Papers mentioned briefly the effectiveness of external shading of buildings but no in depth research on the shading of glazed walls was found. Mandalaki et al (2012, p. 2574) described external devices as *"valuable machines of improvement of the quality of the interior space in office buildings with less energy consumption"* due to their different geometric configurations, and called for the need for more research to be done on numerous aspects of external shading (Mandalaki et al, 2012). The design of appropriate shading devices should be done at the preliminary stages of any design project where comprehensive research and analysis of climate and building requirements will lead to optimized shading designs (Tzempelikos & Athienitis, 2007).

Therefore, based on all the above mentioned advantages of external shading devices, this study aims to quantify the potential energy savings achievable by fixed external shading. Computer simulation was used to simulate the potential energy savings of applying four types of shading devices; horizontal overhangs, vertical side fins, horizontal louvers and vertical louvers. The shading devices were tested on the South, West and East facades in both summer and winter seasons.

This report will first present information obtained from relevant researches found in existing literature which lead to the main aims and objectives of the study. The methodologies used will be explained in details followed by a comprehensive presentation of the results acquired and their discussion. Finally, the main conclusions of this study will be mentioned along with recommendations for future studies to address knowledge gaps that were identified in the literature. References used in this study are found at the end of the report.

2. Literature Review

The potential savings achieved by using external shading devices is widely explored in existing literature. Various methodologies have been used to do the same. The most common method used is the simulation method where energy simulation software is used to detect potential savings achieved using external shading devices. This section will highlight the findings that are most relevant to this study, showing results form studies performed mostly in the region.

It was found that some papers investigated automated louvers coupled with lighting controls. Hammad & Abu-Hijleh (2010), for example, investigated the potential savings in annual energy achieved by incorporating dynamic external louvers on an office building in Abu Dhabi. The methodology used was computer simulation where the IES-VR software was used as the simulation tool. Their results show that there was no significant difference in savings between using dynamic louvers and fixed louvers (at an optimal angle), where the difference was almost 3% only. Thus, it was concluded that it is not worth employing such dynamic louvers system in the climate of the UAE since the extra cost and effort in doing so is not huge (Hammad & Abu-Hijleh, 2010). A fixed louvers system is therefore more practical and cost-effective. For this reason, this study focused on fixed shading systems.

A similar study studied the effect of adding dynamic external roller shades coupled with automatic lighting controls on the energy consumption of on office building in Montreal. The parameters they covered included window size, shading and lighting systems' properties and control. The results were simulated using numerical formulae that were developed for this study. The main finding was that integrating lighting controls with the shading system can cause 77% energy savings due to lower electricity demands for lighting and 16% savings due to less cooling loads when the window to wall ratio is 30%. The study concluded that high savings can occur if shading and lighting systems were automated, depending on the building orientation and location (Tzempelikos & Athienitis, 2007).

It was observed that literature was more focused on static shading devices. The main conclusions, relevant to this study, are noted in the following paragraphs.

A study looked at the effect of both horizontal and vertical louver shading devices on energy consumption through the use of TRNSYS software. Horizontal louvers were considered for the South facades while vertical louvers were considered for the East and West facades. They looked at buildings in Mexico, Egypt, Portugal and Spain. The results show that higher energy savings were achieved in higher latitudes (Cairo, Lisbon and Madrid) since their received higher solar radiation and temperatures. However for London, the shading caused an increase in heating loads during the winter. Thus, it is advised to use automated louvers in cold climates. It was found that energy savings can go up to 60% with horizontal shading on the South and vertical shading on the East and West (Palmero-Marrero & Oliveira, 2010).

Similarly, study looked at the effect of fixed horizontal louvers on the South facade and their effect on energy savings in four cities in Italy. Various configurations of the horizontal louvers were simulated (different slat lengths and angles). Computer simulation was used where the Transient Systems Simulation Program (TRNSYS) was used. The results show that the effect changes with the time of the day, season as well as location. For example, the total loads simulated where highest for the city of Milano because it has the highest latitude which makes it the coldest of the four, thus heating loads contributed mostly to the annual energy loads of the building. It was found that for Milano, 70% savings where achieved in the summer and 40% was achieved in the winter when the optimum configuration was applied (Datta, 2001).

Bellia et al. (2013) studied the effect of shading devices on energy demands of a typical office building in Italy. It compared the impacts in three cities which have different climates. The result showed that incorporating shading devices on buildings in hotter climates is more effective than colder climates, where the savings in Milan (cold climate) were simulated to be 8% as opposed to 20% in Palmero (Bellia et al. 2013).

Ebrahimpour & Maerefat (2011) looked at the impact of using advanced glazing types and overhangs and vertical fins on the energy consumption of a residential building in Iran. The study looked at the effect when the shading is fixed on the South, North, West and East facades. The study was carried out using the computer simulation method where the software EnergyPlus was used. The results show that adding the shading devices resulted in higher energy savings than using double-glazed panels or low emissivity panels on all orientations. This implies that the use of advanced glazing technologies in addition to shading devices will result in higher energy savings (Ebrahimpour & Maerefat, 2011).

Gutierrez & Labaki (2007) carried out an experiment to investigate the thermal performance of three different shading devices (horizontal louvers, vertical fins and eggcrate) on the North and West façades in Brazil. The materials tested were concrete and wood. The test cells and shading devices were built in a city in Sao Paulo. The experiment ran for a year to cover the different seasons. The results show the horizontal lovers are the more efficient shading type for both North and West facades. The vertical fins performed worse on the West facades where the results it gave were very similar to the base case. As for the materials, concrete resulted in higher savings, although wood has higher insulation properties. The reason given was that concrete has higher thermal mass which allows it to absorb the heat and dissipate it in the night time with reduces any heat build up between the louvers and the window. The authors emphasize the importance of location (latitudes) of the country in which the shading device is being tested, stating the need to review generic guidelines deduced from shading studies before its application (Gutierrez & Labaki, 2007).

Another study looked at the effect of having vertical louvers on the North, South, West and East elevations on the temperature reduction in a residential building in Egypt. The TAS simulation software was used. The study showed that the louvers worked best at a length of 100 cm, and was highly effective on the South, West and East elevations resulting in a decrease of 2 degrees. The louvers were less effective on the North elevation (Ahmed, 2012).

Sherif et al. (2012) looked at the effect of different parameters of solar screens on energy consumption in a residential building in Egypt through computer simulation. The solar screens were tested on the North, South, West and East orientations. The software EnergyPlus was used. The results show that optimum configurations of the solar screens caused up to 30% savings in the South and West, 25% in the East and 7% in the North (Sherif et al., 2012). It is deduced that shading on the North is not that important since it is not exposed to direct sunlight.

Al-Tamimi & Fadzil (2011) used computer simulation to study the impact of external shading devices on indoor temperatures of a high-rise residential building in Malaysia. Eggcrate, horizontal overhangs and vertical fins where investigated. The results show that the most effective shading device used was the eggcrate, resulting in a reduction of 4 degrees. The shading device that performed the worst was the vertical shading (Al-Tamimi & Fadzil, 2011).

From the literature review, it can be concluded that shading is mostly effective on the South, West and East facades, rather than the North due to its least exposure to direct sun radiation. Also, it is deduced that fixed shading devices are more practical for the climate of the UAE. Moreover, most papers reviewed emphasized on the importance of modifying general guidelines of shading devices application by performing calculation specific to the location of the building. In addition, it was found that horizontal and vertical shading devices have different impacts on energy consumption. The methodology most commonly used to quantify potential energy savings was found to be computer simulation software tools.

As for the UAE status quo on research on building energy performance in general, it was found that many studies have been carried out in the UAE using different methods to check the impact of various strategies on energy consumption. The effect of insulation materials (Friess et al, 2012), effect of courtyards (Al Masri & Abu-Hijleh, 2012), effect of desiccant cooling (Francis, 2011), effect of urban design (Al Sallal & Al Rais, 2012) to mention a few. Very little research has been found on shading effect in general on energy consumption in the UAE.

Based on these findings, the main aim and objectives of this study are explained in the following section of the report.

3. Aim and Objectives

The primary aim of this study is to quantify the impact of different types of fixed external shading devices on the total annual energy consumption of an office building in Dubai. This study acknowledges the need for glazed elevations to contribute to the overall aesthetic value of the building and city but however it also highlights the importance of employing shading devices due to their advantages in contributing to energy savings as well as achieving thermal comfort. This study will mainly focus on fixed external devices since they were proven to be more effective than internal shading devices at blocking solar radiation. Fixed shading devices will be investigated since it has been proven that they are more practical in the UAE context than dynamic shading devices. The shading devices that will be studied are: horizontal overhangs, horizontal louvers, vertical fins and vertical louvers.

The objectives of this research project are the following:

1. Look at the performance of each of the above mentioned shading devices in terms of energy savings.
2. Quantify possible savings by the basic applications of these shading devices by the use of an energy modeling simulation tool.
3. Find the influence of the facade on which the shading device is placed on the potential energy savings.
4. Discuss and explain possible implications of outcomes and link results to other results found in relevant literature explained in previous section.
5. Highlight knowledge gaps relevant to this topic and provide recommendations accordingly

4. Methodology:

This section will highlight the methodologies used to achieve the before mentioned objectives of the research. First, the main research parameters are mentioned followed by the criteria followed for the literature review is explained. Then the base case used in the simulation will be described. A description of how the shading devices were selected is then mentioned. This is followed by the detailed description of the tested shading devices. Finally, details of the actual simulation and software are presented.

Defining research parameters

An existing office building in Dubai is modeled in IES-VE to be used to fulfill the aim of this study for all possible scenarios. A number of parameters will be simulated in various scenarios to quantify the potential energy savings of using four different shading devices for the building. The main result of this study will be the daily energy consumption, annual energy consumption and annual energy savings. Evaluation of each shading device will be based on its energy performance in comparison with the base case and other shading devices. Materials, shading co-efficient of all building elements (glazing, walls and shading devices) are constant. An optimum configuration of all shading devices on all facades will be simulated to see the maximum potential energy savings. The main parameters that are tested are:

1. The difference in energy consumption between the building with and without the shading devices; horizontal overhangs, vertical side fins, horizontal louvers and vertical louvers.
2. The effect of adding the shading devices on the South, East and West elevations.
3. The potential energy savings that can be achieved using the shading devices.

Literature review criteria

A comprehensive research was completed on current existing literature which has investigated the same topic using various research methods. The criteria used were the following:

- Existing literature on various approaches used to reduce energy consumption in buildings (residential and commercial) in the United Arab Emirates and other regions with similar climate to that of the UAE. This is done to learn the most common perspective from which energy consumption of buildings is looked at, which helps know where the importance of windows (design, sizes) and shading devices lie in existing research. Also, this will lead to the identification of knowledge and research gaps which can potentially be covered in this study or included in the recommendations section.

- Current research that is being carried out on shading design typologies in the UAE and their attributed reductions in energy consumption. Different methodologies used will be studied to determine whether the selected method is in fact that optimal and shortcomings of the methods will be discovered.
- References on shading design to be able to design the shading devices to be simulated according to prescriptive guidelines found from former researches.
- Previous research done on the use of the four shading strategies to be covered in this study (horizontal overhangs, horizontal louvers, vertical fins and vertical louvers). This will provide information on how these shading devices were previously designed and studied.

Base case building

The base case building used for this study is an existing building in Dubai. The building, named "Al Shoala" building, is located in the city centre of Dubai. It is divided into three zones; two high rise buildings divided by a middle low-rise building. The building used in this simulation is one of the high-rise buildings; zone C, which is an office building. One floor of this building was simulated with the assumption that the results are replicated for all floors of the building. Figure 1 is an image of the building. The black rectangle shows one of the floors in the building.

Figure 1 Photo of office building used for the simulation (Author)

The external wall construction of the building is (from outer to inner): lightweight concrete blocks, polyvinyl chloride (PVC) insulation, and gypsum board. The external glazing is comprised of two 6 mm glass sheets with a 12 mm gap in between. The floor area simulated is 1470 m². Total wall area is 422 m² and the glazing area is 345 m².

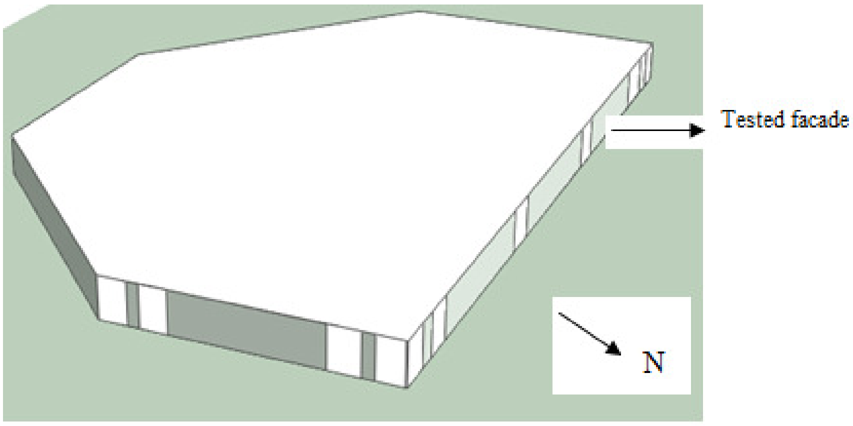


Figure 2 Building Model in IES (IES-VE)

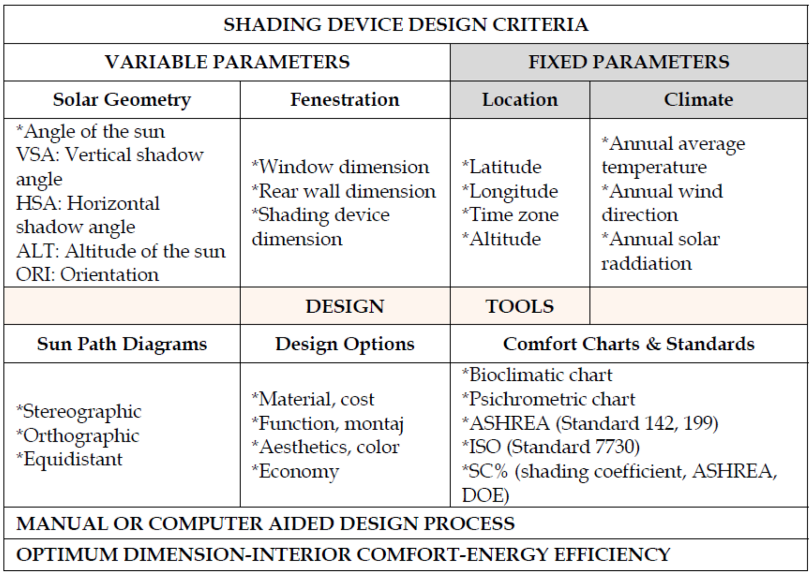
Selection of shading devices

Through the literature review, it was evident that the most common effective fixed external shading devices that are typically used are the horizontal overhangs (deep and shallow), vertical fins (deep and shallow), horizontal louvers, vertical louvers and egg-crate (combination of horizontal overhangs and vertical fins. Accordingly, the four shading devices selected for this study are deep horizontal over hangs, deep vertical fins, horizontal louvers and vertical louvers.

Shading devices' design

Table 1 shows the shading device criteria summarized in a concise table which gives a clear guideline on the factors that should be considered whilst designing shading devices (Yüceer, 2012).

Table 1 Shading device design criteria (Yüceer, 2012)



SHADING DEVICE DESIGN CRITERIA			
VARIABLE PARAMETERS		FIXED PARAMETERS	
Solar Geometry	Fenestration	Location	Climate
*Angle of the sun VSA: Vertical shadow angle HSA: Horizontal shadow angle ALT: Altitude of the sun ORI: Orientation	*Window dimension *Rear wall dimension *Shading device dimension	*Latitude *Longitude *Time zone *Altitude	*Annual average temperature *Annual wind direction *Annual solar raddiation
	DESIGN	TOOLS	
Sun Path Diagrams	Design Options	Comfort Charts & Standards	
*Stereographic *Orthographic *Equidistant	*Material, cost *Function, montaj *Aesthetics, color *Economy	*Bioclimatic chart *Psichrometric chart *ASHREA (Standard 142, 199) *ISO (Standard 7730) *SC% (shading coefficient, ASHREA, DOE)	
MANUAL OR COMPUTER AIDED DESIGN PROCESS			
OPTIMUM DIMENSION-INTERIOR COMFORT-ENERGY EFFICIENCY			

1) Horizontal overhangs

The depth of horizontal overhangs was depicted by different stages of numerical formulae. Firstly, the exact size of the windows to be shaded was noted. Then, the latitude and longitude of Dubai's location was found: 25.27 and 55.30 respectively. This information was entered into the Solar Tool of the Ecotect software. The timings which required shading where identified: June 15th and December 15th at 8 am, 10 am, 12 pm and 2 pm. Vertical Shadow Angle (VSA) angles where automatically generated for these timings. Finally, the following formula was used to calculate the overhang depth:

Depth = [height / tan (VSA)] – wall thickness

Eight calculations were made then divided by 8 to find the average overhang depth. The result was found to be 1500 mm. Thus, the depth of the overhangs used in this study is

1500 mm deep. The simulation model is of the overhangs is shown in figure 3.

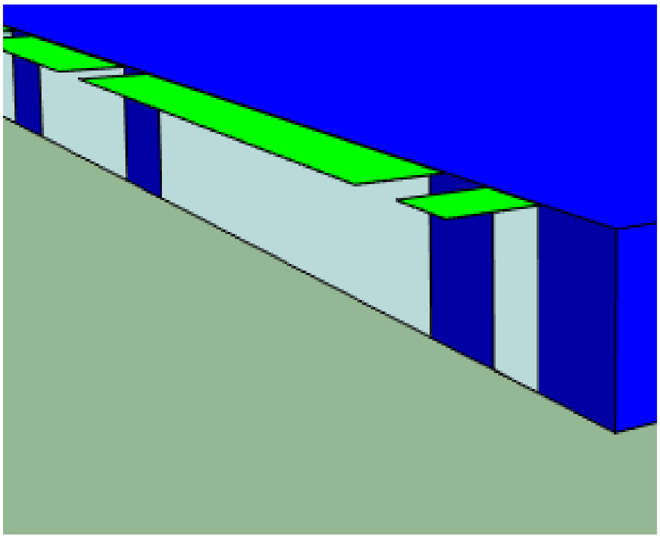


Figure 3 Simulation model of horizontal overhangs

1) Vertical fins

The size of the vertical fins was determined based on findings from the literature review which demonstrate how vertical fins are commonly used (Carmody & Haglund, 2006). There are two main types of vertical fins; deep and shallow. Since it was proved that deep vertical fins result in higher energy savings, they were used in this study. Vertical fins are usually placed on either side of a window. However, since in this building the width of two of the windows is 1200 mm, a vertical fin has been placed every 1300 mm, having a total of 9 vertical fins across the window's length. The dimensions of the vertical fins are shown in figure 4.

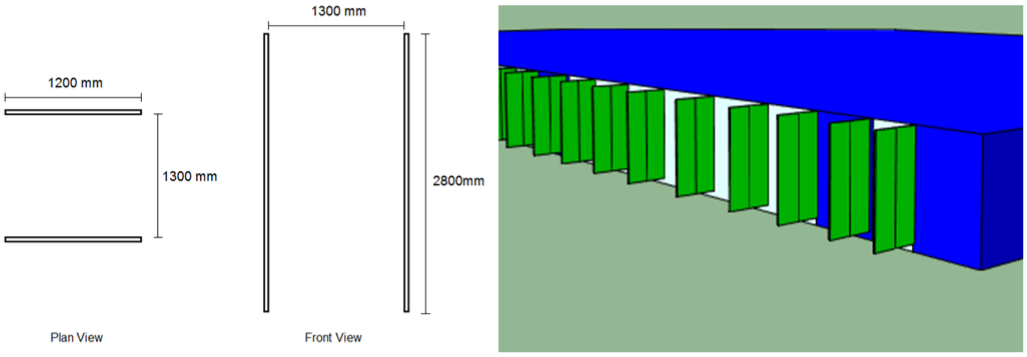


Figure 4 Plan and front view of vertical fins simulated and simulation model of vertical fins

2) Horizontal louvers

Horizontal louvers vary greatly in designs and sizes. The size of the horizontal louvers was determined based on findings from the literature review which demonstrate how horizontal louvers are usually designed (Carmody & Haglund, 2006). The slats of the horizontal louvers used in this study were 5 mm thick and 200 mm wide. The distance between the slats is 200 mm. The length of the louvers was set according to the width of the window, where it was a maximum of 1200 mm and a minimum of 1000 mm, based on the window sizes. A side view of the horizontal louvers is shown in the figure 5.

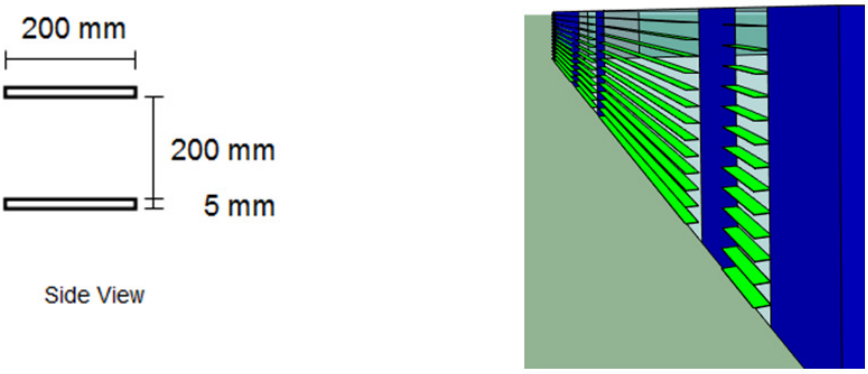


Figure 5 Side view of horizontal louvers used, and simulation model of horizontal louvers

3) Vertical louvers

Vertical louvers vary greatly in designs and sizes. The size of the vertical louvers was determined based on findings from relevant literature which demonstrates how vertically louvers are typically designed (Carmody & Haglund, 2006). The slats of the vertical louvers used in this study were 5 mm thick and 200 mm wide. The distance between the slats is 200 mm. The height of the louvers was 2800 mm, based on the height of the window, since it is required that the vertical louvers span the whole height of the window. The dimensions of the vertical louvers are shown in figure 6.

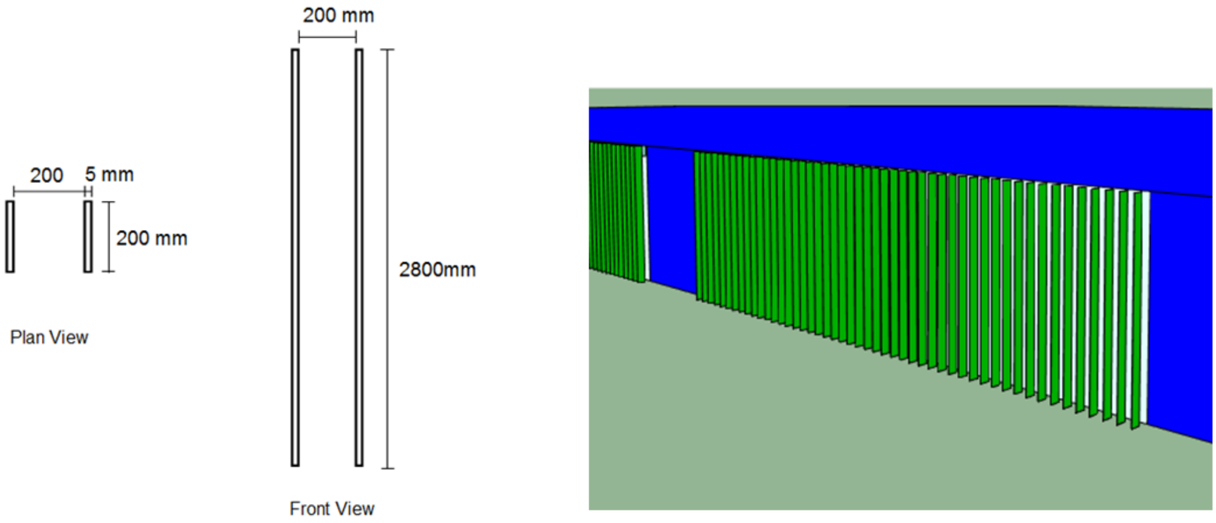


Figure 6 Plan and front view of vertical louvers used and simulation model of vertical louvers

Simulation Software

The computer simulation method is widely and consistently used in the literature to undertake similar researches to the one presented here, as well as various building-energy related simulations. It offers a cost-effective advantage where expected results of real life mock ups are simulated without going the bother of building a real life model. Compared to real life experimentation, it is less time consuming, more cost effective and calculates results that are very close to real life results. Kotey et al. (2009) study compared the results acquired when running the same research using real life experiment and simulation. They found that the difference between real life and simulation was less than 0.05. The disadvantages of one over the other could not be determined since they were very much in agreement (Kotey at al., 2009).

Computer simulation was used to quantify the differences in energy consumption as a result of using the different shading devices. The software Integrated Environmental Solutions- Virtual Environment (IES-VE) was used. IES- VE is a reputable simulation software that was used consistently in studies similar to the one described in this report. It is used widely by professionals in real-building design process as well as by researchers. It has the advantage of being able to process a huge amount of information is a very short period of time. IES-VE has a variety of different applications. For this report, the Model It app was used to model the base case building and the variations of shading devices. This was followed by the use of the SunCast which calculates the amount of light hitting each surface of the building, thus is important for shading calculations. The energy simulation was then done using the Apache app where the construction and thermal (operational profiles) templates were assigned to the building model. The last app used was the Vista app which displays the results of the simulations in graphs, tables and reports.

Simulation scenarios

The operational profile simulated was that the building is operated from 6 am to 8 pm every day. The air conditioning system was set at a constant temperature of 23 degrees. The simulations were carried out for both the summer (June 15th) and winter (December 15th) seasons. The shading devices described above were simulated on three different orientations; the South, West and East. The energy consumptions will be compared to the base case energy consumptions in the South, West and East orientations. This was done to check the performance of each shading device on each orientation. Following this, a simulation of the optimal configuration of shading devices on optimum orientation was carried out to calculate the maximum amount of energy savings possible.

5. Results and Discussion

This section will display the results of the simulations of the different impacts of the above mentioned shading devices on the different orientations. It will begin with an explanation of a sun path figure for both summer and winter seasons. The results of the base case will first be presented, following by the results of the shading devices. For each shading device, three graphs are presented; the energy consumption during the whole day of both 15th of June (summer) and 15th of December (winter). Each graph shows the energy consumption of that certain scenario along with the energy consumption of the base case, for comparisons sake. Because the building is not symmetrical, there are 4 different base case energy consumption rates; one for each facade. At the end of the description of the results of each shading device, a bar chart showing the annual potential savings caused by that shading device on the three different orientations. It gives a clear representation of the performance of the shading device on different orientations. The results will be analyzed and possible interpretations will be discussed.

Sun path diagram

Figure 7 shows the sun path through different seasons (NASA, 2001). The red line shows the sun path during the summer and the green line shows the sun path during the winter. The centre of these arcs marks the middle of the day; noon at 12 pm. It is evident from the figure that the direction which has the maximum exposure to the sun is the South direction, in both seasons. The East direction is exposed to direct sun radiation in the early part of the day while the West direction is exposed to direct sun radiation in last part of the day until sun set. In the summer, it is noted that the sun reaches higher altitudes than in the winter. Thus, during the summer the incident angles of the sun rays on the building surfaces are higher with less penetration, while the opposite is true for the winter, where the sun is lower thus lower angles with higher penetration.

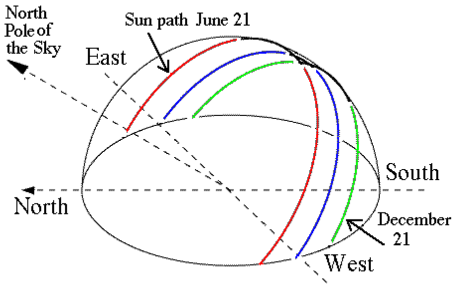


Figure 7 Sun path diagram (NASA, 2001)

Base case

The figures 8 and 9 show the energy consumption during a day in summer and winter on a typical working day in the existing building as is, where the facade that is being tested is facing the North. The summer graph shows that at the beginning of the day the energy consumption is low and it starts increasing at 6 am. This is mainly because the operational profile of the simulation is set to start at 6 am, which is when the air-conditioning system is turned on. It reaches 23 KW at 10:30 am then decreases to 21 KW at around noon. It then starts to increase again reaching a day peak of 25 KW at 3:30 before it continues to decrease of the rest of the day. As for the winter graph, the energy steadily increases until it peaks at 25 KW in the afternoon, and then steadily decreases.

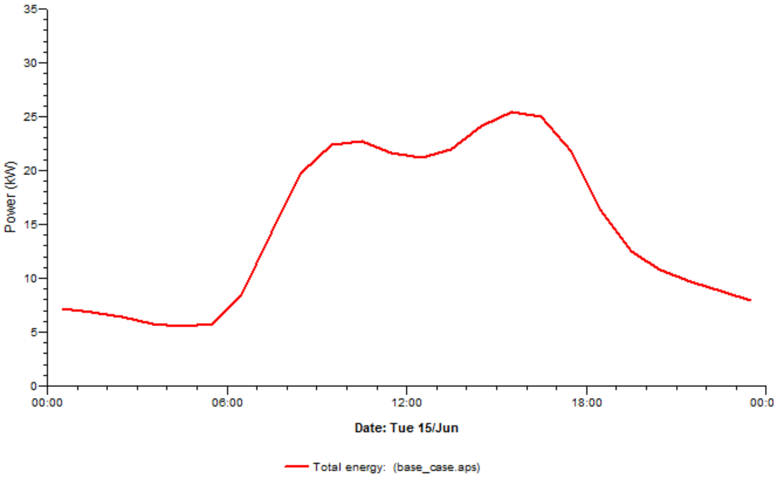


Figure 8 Graph showing energy consumption on 15th June in the base case (IES-VE)

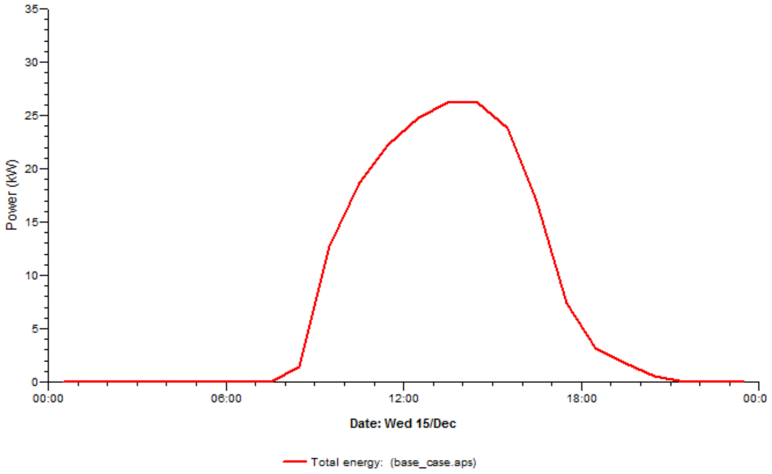


Figure 9 Graph showing energy consumption on 15th December in the base case (IES-VE)

The patterns explained above are repeated for the rest of simulation graphs since the sun path is the same. The energy consumption changes according to different shading devices used and according to the elevation it is placed on.

Shading devices

1) Horizontal overhangs

a. South elevation

Figures 10 and 11 show the energy consumption of the building throughout a summer and winter working day. The horizontal overhangs were placed on the South elevation, which means that the rest of the elevations are not shaded. For the summer graph, it shows that at noon, when the sun is in the South, the consumption actually increases slightly over the base case. This can be caused by the heat entrapment effect, where it could be that although less direct sun radiation is hitting the windows itself due to the shading effect, the shading devices are being heated up by the sun hitting them from the top (when in South) causing heat to be trapped between the shading device and the window, leading to higher cooling loads.

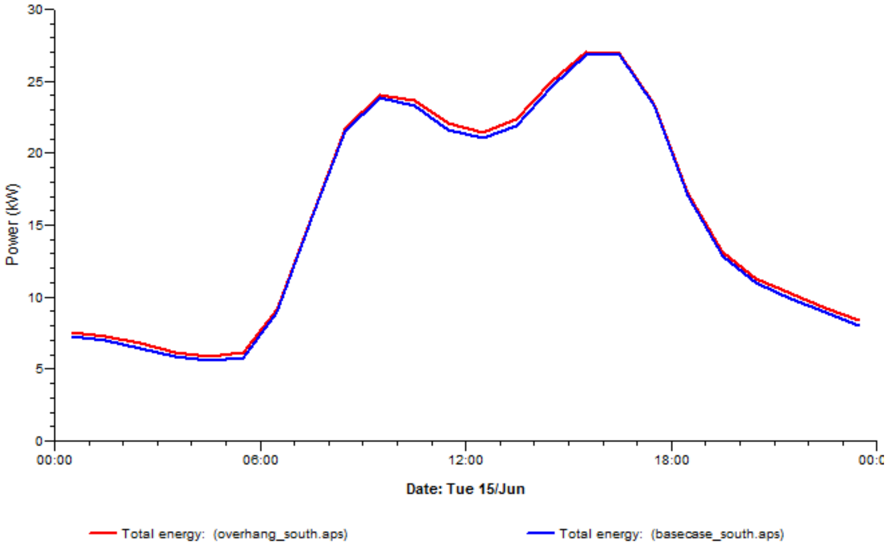


Figure 10 Graph showing energy consumption on 15th June in the overhangs/South/summer scenario (IES-VE)

As for the winter graph, the energy consumption with the overhangs is well below the base case when the sun in the South.

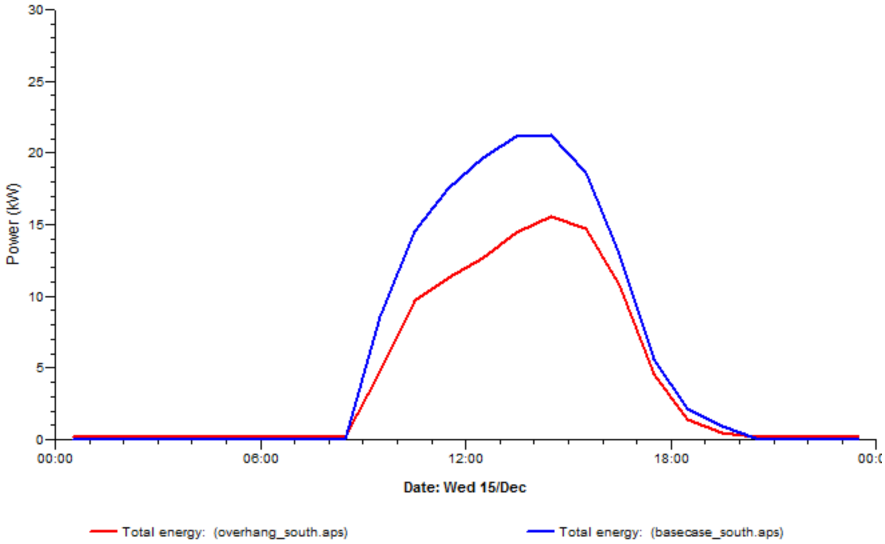


Figure 11 Graph showing energy consumption on 15th December in the overhangs/South/winter scenario (IES-VE)

b. West elevation

Figure 12 and 13 show the energy consumption of the building throughout a summer and winter working day. The horizontal overhangs were placed on the West elevation, which means that the rest of the elevations are not shaded. For the summer graph, the energy consumption is noticeably lower when using the overhangs in the later part of the day when the sun is in the West, which shows that overhangs are effective in the West.

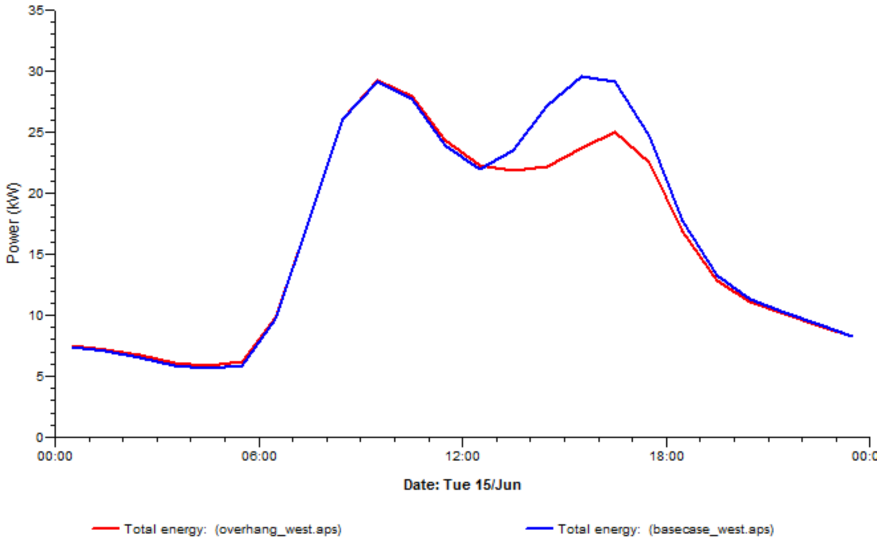


Figure 12 Graph showing energy consumption on 15th June in the overhangs/West/summer scenario (IES-VE)

As for the West/winter day, the energy is also lower in the later part of the day, showing that the overhangs are blocking the sun decreasing consumption.

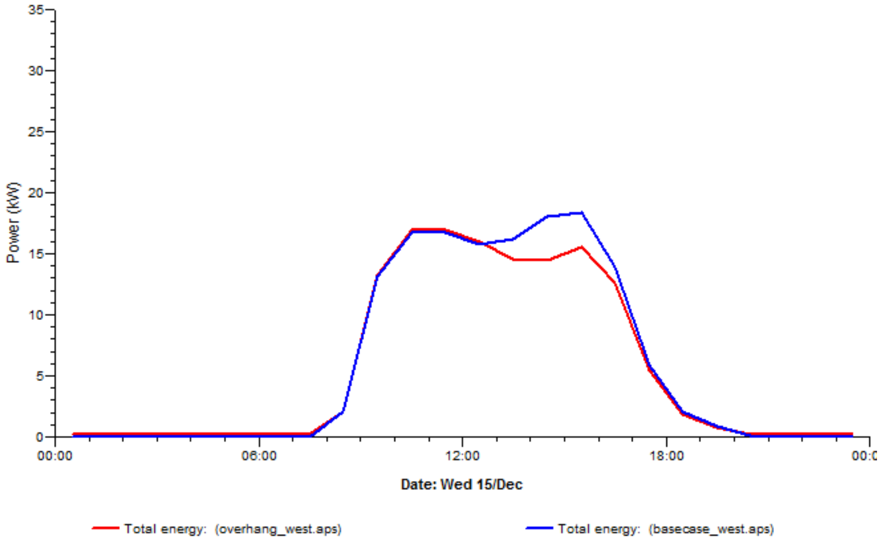


Figure 13 Graph showing energy consumption on 15th December in the overhangs/West/winter scenario (IES-VE)

c. East elevation

Figure 14 and 15 show the energy consumption of the building throughout a summer and winter working day. The horizontal overhangs were placed on the East elevation, which means that the rest of the elevations are not shaded. The East/summer graph's shape is the reverse of the East/winter shape. The energy consumption during the earlier part of the day, when the sun is in the East, is significantly lower than that of the later part of the day, when the sun is in the West.

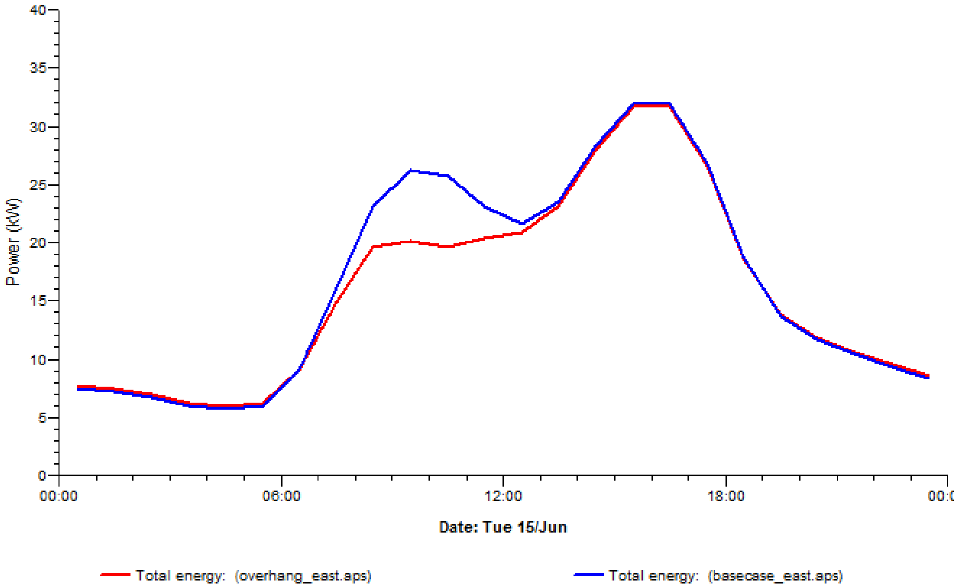


Figure 14 Graph showing energy consumption on 15th June in the overhangs/East/summer scenario (IES-VE)

As for the winter case, again the energy consumption peaks in the later part of the day when the sun is in the West, since there are no shading devices on that side, while the lowest energy consumption occurs in the earlier part of the day when the sun is in the East. This proves that the overhangs perform effectively in the winter as well.

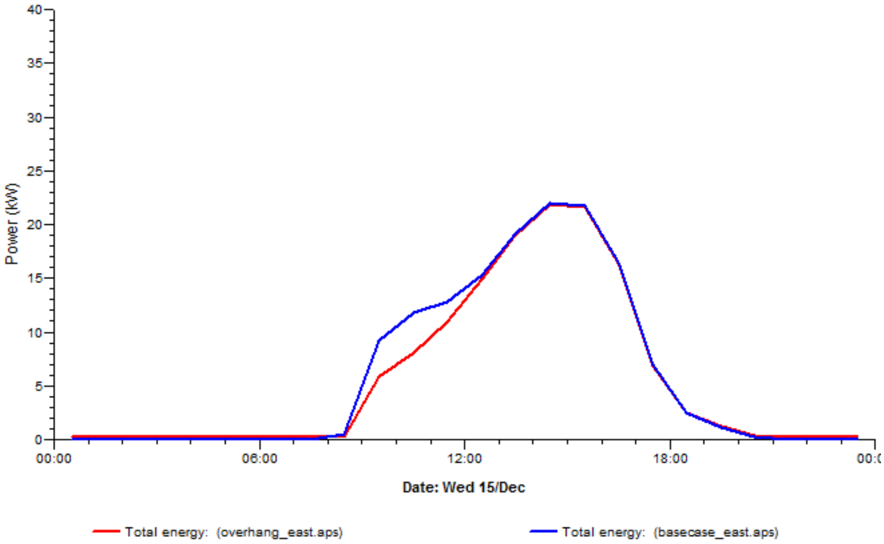


Figure 15 Graph showing energy consumption on 15th December in the overhangs/East/winter scenario (IES-VE)

d. Annual savings

Figure 16 shows the difference in the annual energy consumption (MWh) when the overhangs were fixed on the three elevations, as well as the annual energy consumption of the base case.

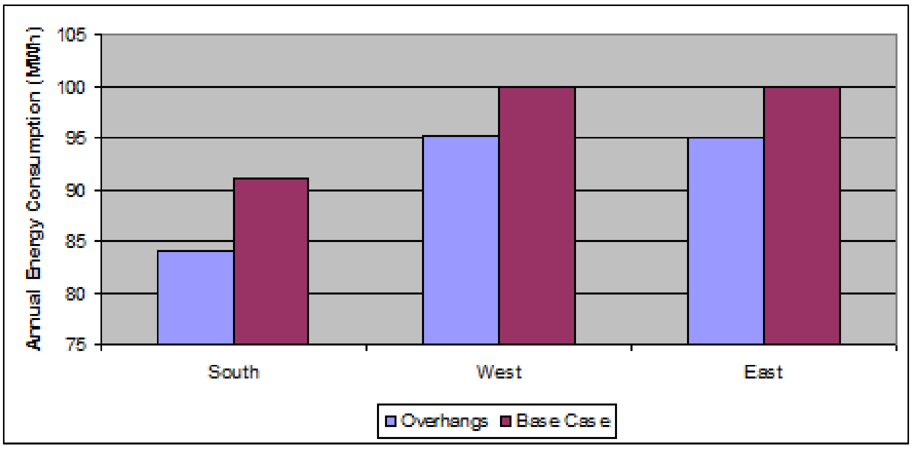


Figure 16 Bar chart showing the annual energy consumption (MWh) for the overhangs on the South, West and East orientations, and the base case

The results show that over the year, the horizontal overhangs perform best on the South elevation, where the annual energy consumption is 84.00 MWh, around 8% less than the base case's 91.20 MWh. The overhangs performed almost equally well on the West and East elevations, where the energy savings where 4.7 % and 4.9 % respectively. The high energy savings caused by the overhangs on the South facades can explained by the fact that the South facade that is exposed to the sun for the most duration.

2) Vertical fins

a. South elevation

Figures 17 and 18 show that, similar to the horizontal overhang section, an identical pattern was simulated for the vertical fins on June 15th, where the lowest energy consumption of 21.5 KW was noted at midday and maximum of 27 KW was noted towards the end of the day. This shows that during the summer, the vertical fins are less effective than the overhangs. This can be caused by one of the following factors: the width of the vertical fins is not deep enough; the distance between the fins is big so not enough window area is covered, or that the 90 degrees angle position does not block enough solar radiation, deeming the vertical fins as ineffective.

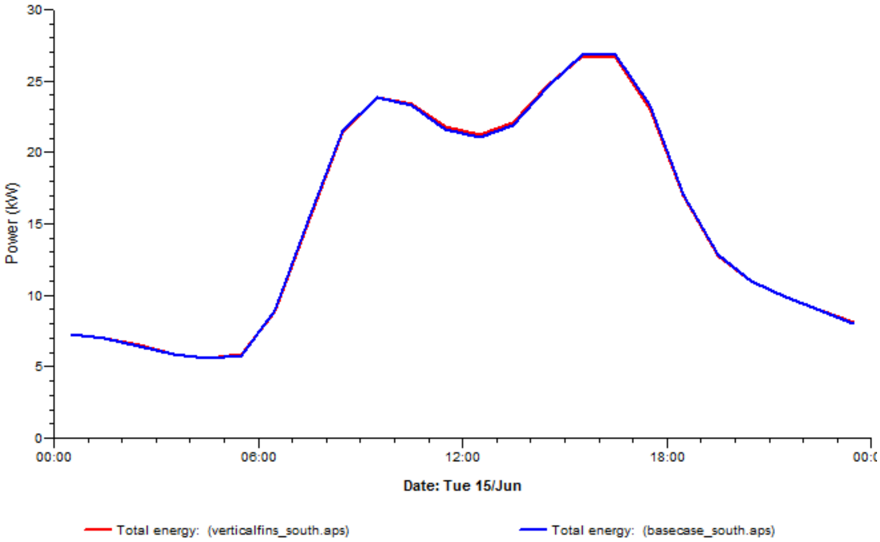


Figure 17 Graph showing energy consumption on 15th June in the vertical fins/South/summer scenario (IES-VE)

The winter case shows that the vertical fins are , figure 18 shows that the vertical fins reduces the energy consumption, but less than the overhangs, making the overhangs more effective in winter.

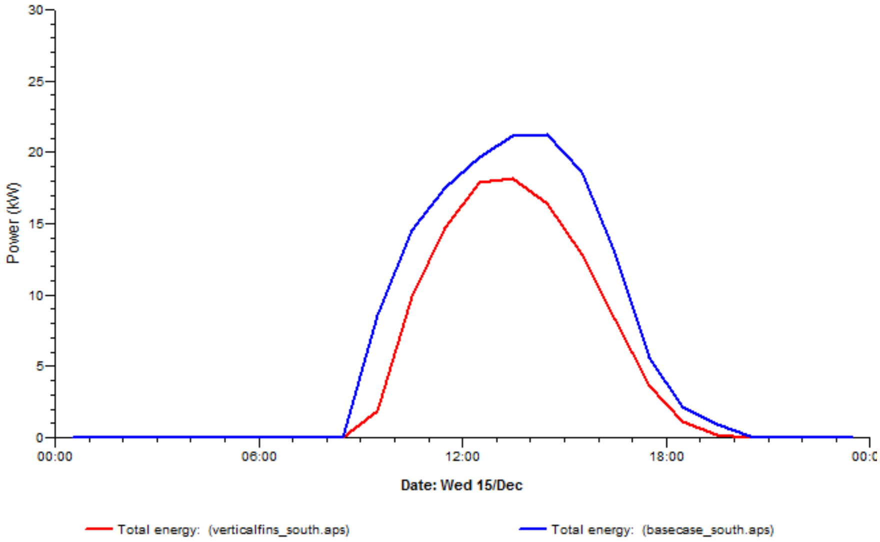


Figure 18 Graph showing energy consumption on 15th December in the vertical fins/South/winter scenario (IES-VE)

b. West elevation

Figure 19 and 20 show the energy consumption for the vertical fins scenarios. The vertical fins/West/summer scenario graph shows that the vertical fins are less effective on the West during the summer than the overhangs in the summer. This can be deduced by the energy consumption that did decrease when the sun is in the West, but with a very slight difference.

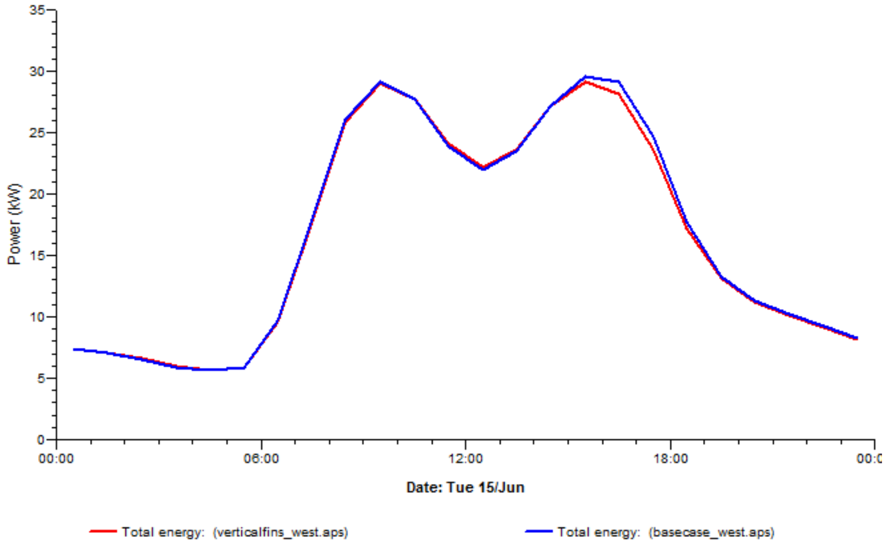


Figure 19 Graph showing energy consumption on 15th June in the vertical fins/West/summer scenario (IES-VE)

As for the vertical fins/West/winter scenario, the graph shows that the energy consumption decreases at the point where the sun is in the West, indicating that the vertical fins are blocking direct sun radiation. Thus it is concluded that the vertical fins on the West facade are more effective in winter than summer. This means that the vertical fins are able to block sun radiation when the sun is at a lower altitude.

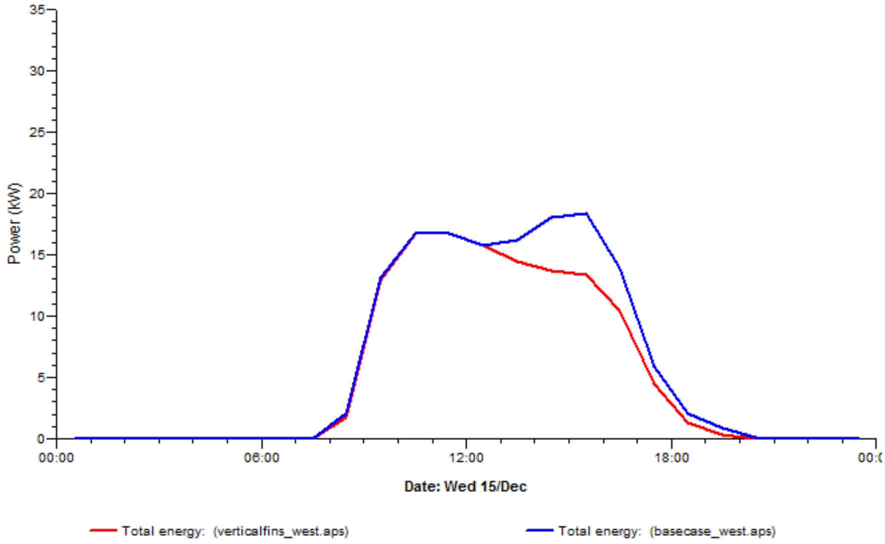


Figure 20 Graph showing energy consumption on 15th December in the vertical fins/West/winter scenario (IES-VE)

b. East elevation

The vertical fins/East/summer scenario (figure 21) shows that the energy consumption during the early part of the day (when the sun is in the East) is lower than that of in the later part of the day (in the West). However, when compared to the overhangs/East/summer scenario, it shows that overhangs are more effective, where the lowest energy consumption was 20 KW while it is 26 KW in this case.

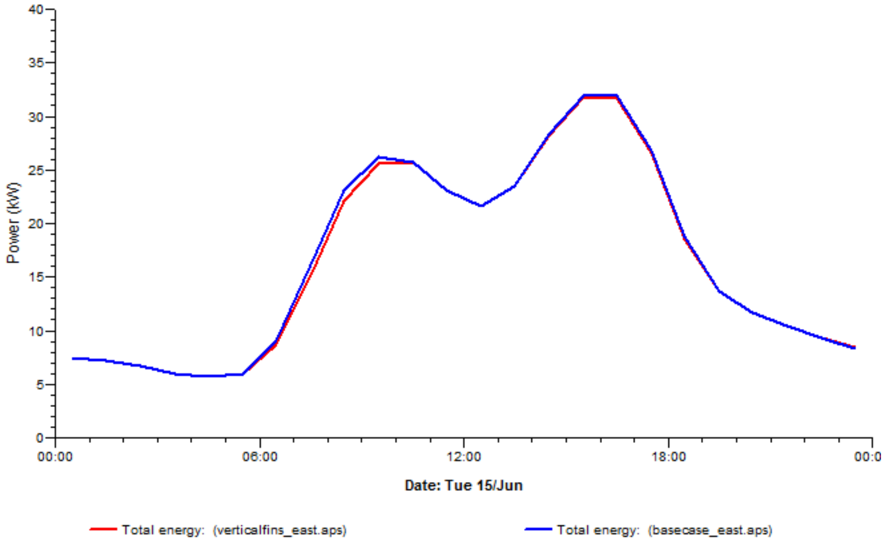


Figure 21 Graph showing energy consumption on 15th June in the vertical fins/East/summer scenario (IES-VE)

The same pattern is observed during the winter (figure 22) where the energy consumption is at the minimum during the early part of the day.

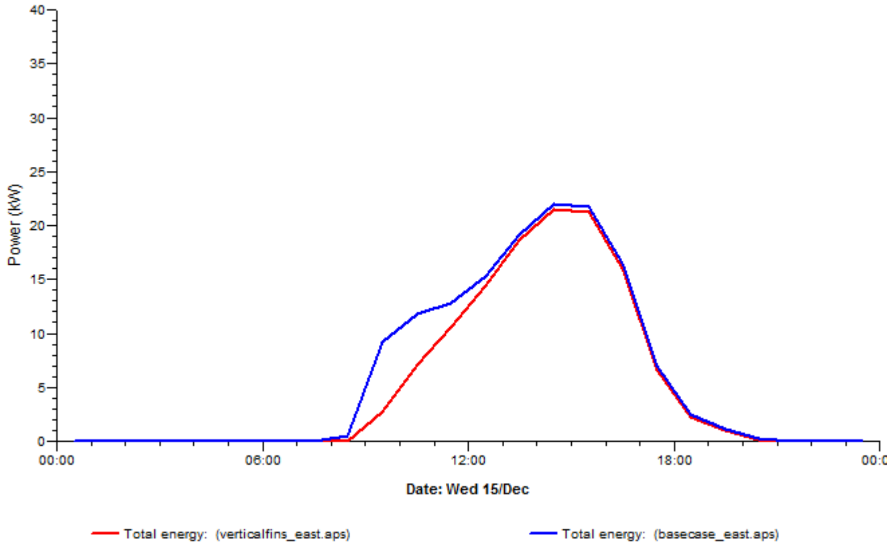


Figure 22 Graph showing energy consumption on 15th December in the vertical fins/East/winter scenario (IES-VE)

c. Annual savings

Figure 23 show the difference in the annual energy consumption (MWh) when the vertical fins were fixed on the three elevations, as well as the annual energy consumption of the base case.

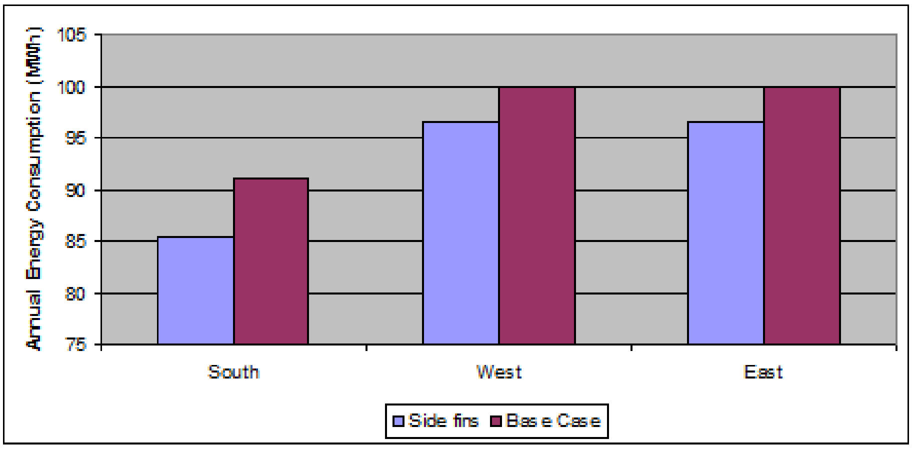


Figure 23 Bar chart showing the annual energy consumption (MWh) for the vertical fins on the South, West and East orientations, and the base case

Similar to the overhangs simulation, it is concluded that through the duration of a year, most energy savings were achieved when the vertical fins are fixed on the South facade where the total energy savings was 6.47% compared to the base, which is lower than the saving achieved with the overhangs. It also deduced that the vertical fins perform similarly on both West and East facades where the percentage savings was almost 3.5% for both.

3) Horizontal louvers

a. South elevation

The horizontal louvers/South/summer scenario (figure 24) is almost identical to the two previous summer/South scenarios explained but with a light difference of 1 KW lower energy consumption during the early part of the day. It is expected that horizontal louvers perform more effectively since they cover a larger area of the window thus blocks more direct solar radiation.

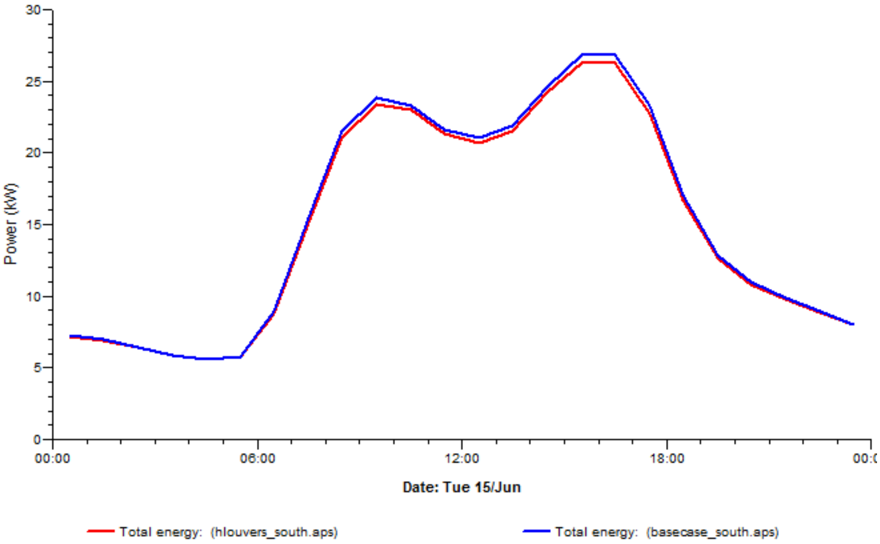


Figure 24 Graph showing energy consumption on 15th June in the horizontal louvers/South/summer scenario (IES-VE)

The horizontal louvers/South/winter scenario (figure 25) achieved higher savings than both the previously explained shading devices scenarios in the South/winter cases.

The highest energy consumption recorded here was 12 KW while it was 16 KW and 18 KW in the overhangs/South/winter and vertical fins/South/winter scenarios respectively.

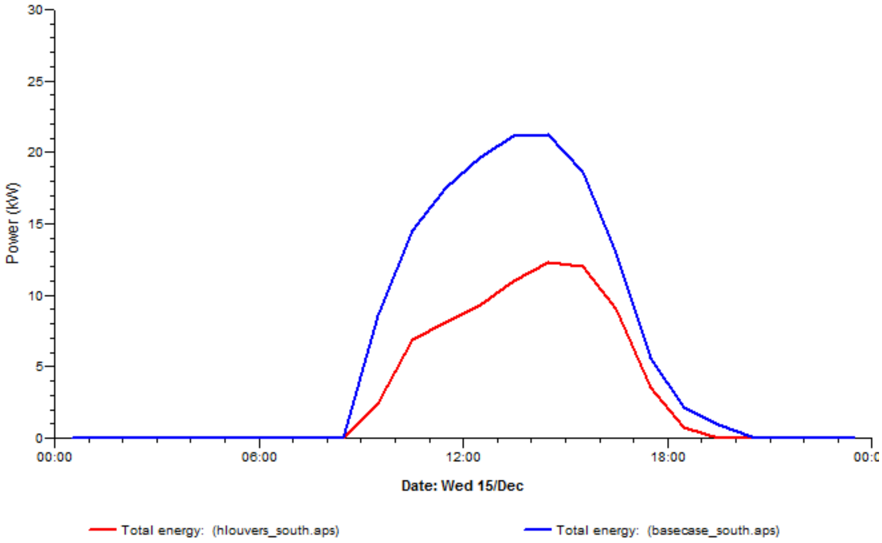


Figure 25 Graph showing energy consumption on 15th December in the horizontal louvers/South/winter cenario (IES-VE)

b. West elevation

The horizontal louvers/West/summer scenario graph (figure 26) shows that the shading device is effective since the energy consumption decreases significantly when the sun is in the West, which shows that the shading devices are able to block the majority of the direct solar radiation. It is also noted that the horizontal louvers perform better than both the overhangs and the vertical fins where the highest energy consumption calculated when the sun is in the West direction is 23 KW, while it was 25 KW and 29 KW for the overhangs and vertical fins respectively.

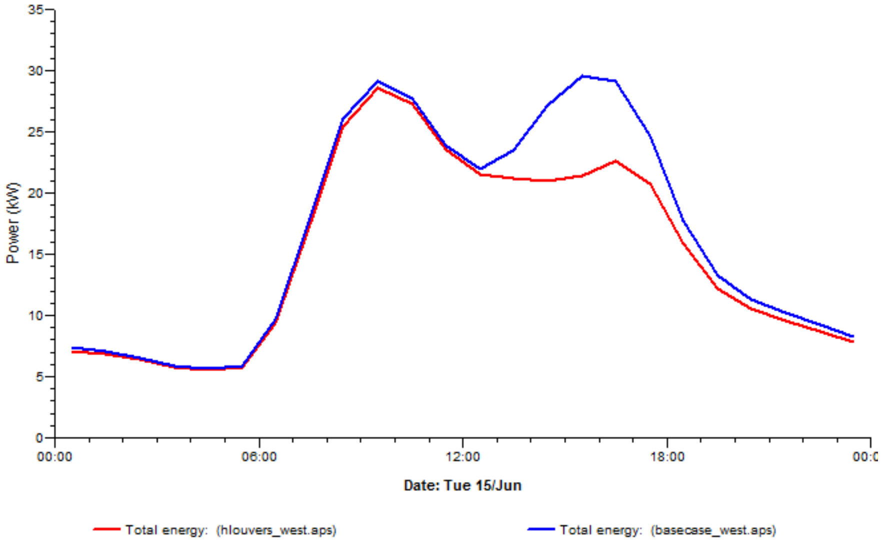


Figure 26 Graph showing energy consumption on 15th June in the horizontal louvers/West/summer scenario (IES-VE)

However in the horizontal louvers/West/winter scenario (figure 27) the results show that the horizontal louvers perform very similar to both the overhangs and vertical fins in the winter time. This can be caused by the lower altitude of the sun which the horizontal louvers are not able to block when they are at 90 degrees angle.

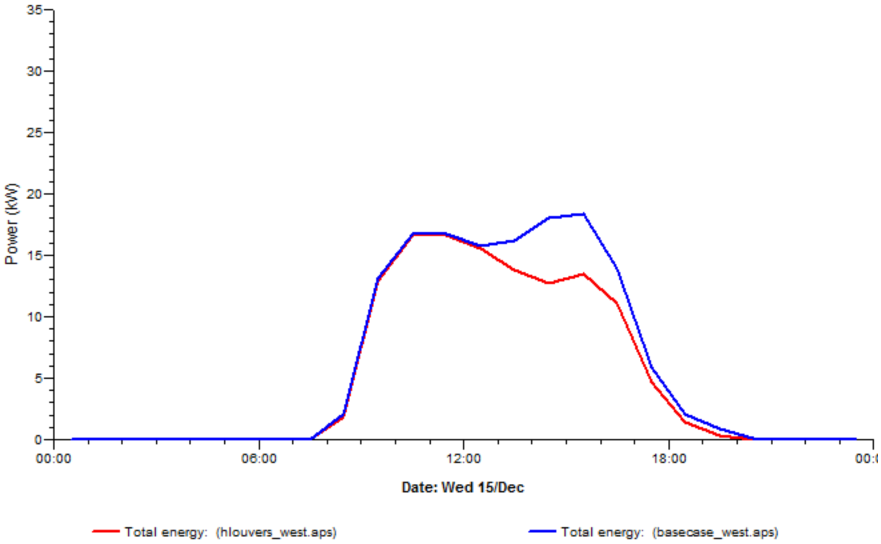


Figure 27 Graph showing energy consumption on 15th December in the horizontal louvers/West/winter scenario (IES-VE)

c. East elevation

Similar to the West/summer case (figure 28) the horizontal louvers performed effectively in the East/summer scenario. It caused higher energy savings than both the overhangs and the vertical fins. The highest energy consumption calculated during the early part of the day when the sun is in the East in this case is 17 KW, while it was 19.5 with the use of overhangs and 29 KW with the use of vertical fins.

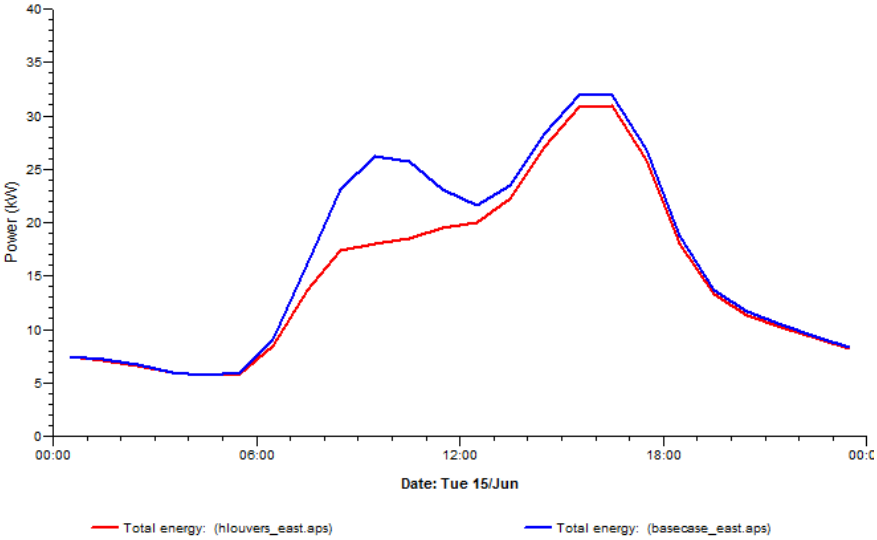


Figure 28 Graph showing energy consumption on 15th June in the horizontal louvers/East/summer scenario (IES-VE)

In the winter case (figure 29), the results were similar to the West case, where the horizontal louvers performed similarly as the overhangs and vertical fins. This shows that the horizontal louvers are more effective in the summer rather than winter, which can be due to the higher altitude of the sun.

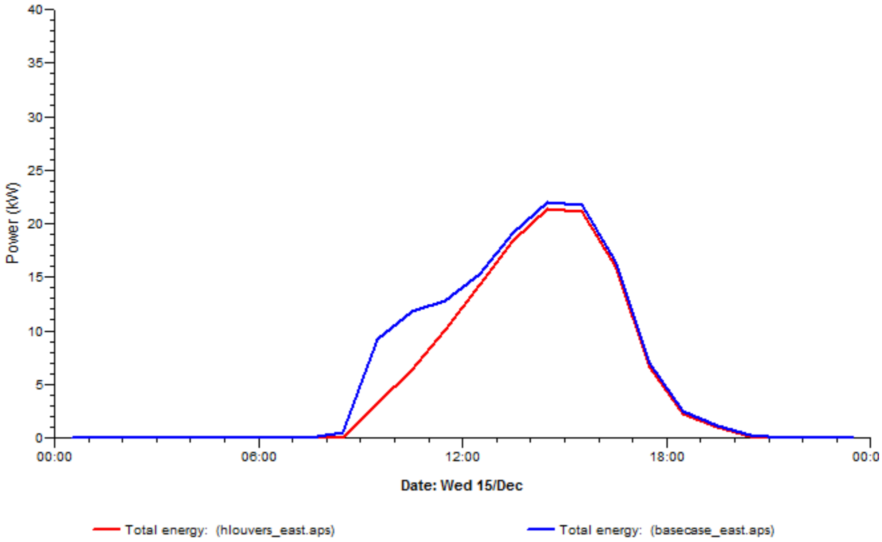


Figure 29 Graph showing energy consumption on 15th December in the horizontal louvers/East/winter scenario (IES-VE)

d. Annual savings

Figure 30 show the difference in the annual energy consumption (MWh) when the horizontal louvers were fixed on the three elevations, as well as the annual energy consumption of the base case.

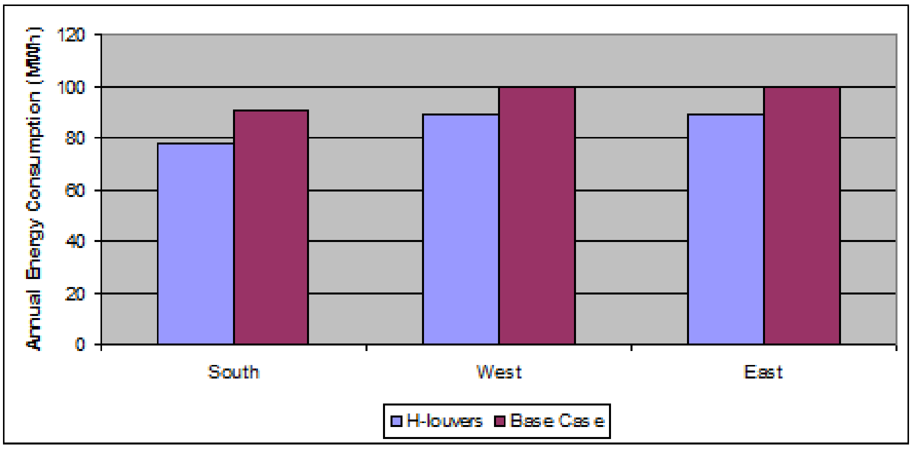


Figure 30 Bar chart showing the annual energy consumption (MWh) for the horizontal louvers on the South, West and East orientations, and the base case

Similar to the previously discussed shading devices simulation, it is concluded that through the duration of a year, most energy savings were achieved when the horizontal louvers are fixed on the South facade where the total energy savings was 14.58 % compared to the base, which is highest than both previous shading devices. It also deduced that the horizontal louvers perform similarly on both West and East facades where the percentage savings was almost 10.3% for both, which also ranks them higher than both previously discussed shading devices.

4) Vertical louvers

a. South elevation

Figures 31 and 32 show the energy consumption of the building when the vertical louvers are placed on the South façade, both in the summer and winter seasons. For both the summer case and winter case, it shows that the vertical louvers performed very similarly to all the previously explained shading devices.

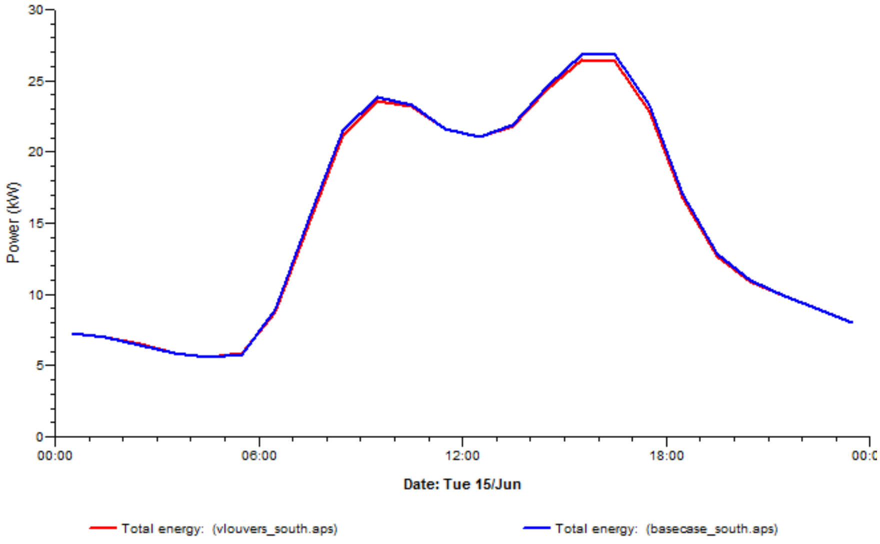


Figure 31 Graph showing energy consumption on 15th June in the vertical louvers/South/summer scenario (IES-VE)

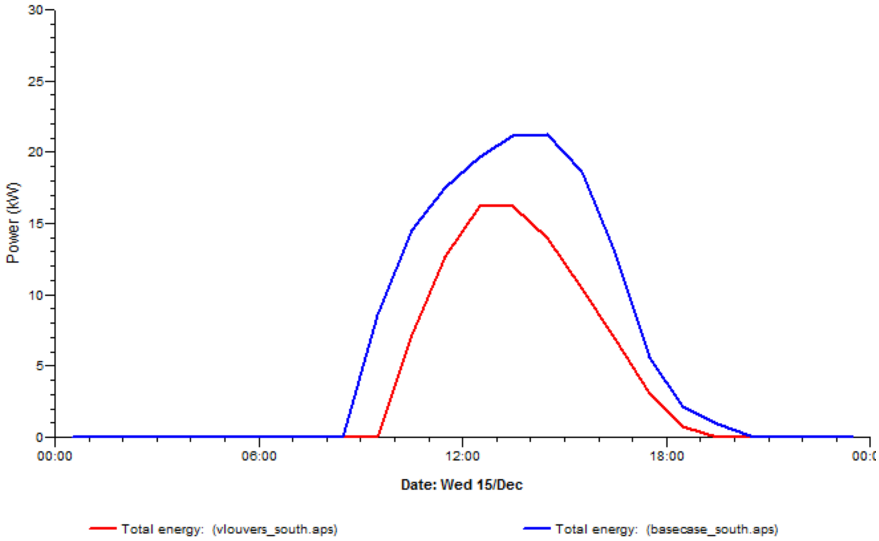


Figure 32 Graph showing energy consumption on 15th December in the vertical louvers/South/winter scenario (IES-VE)

b. **West elevation**

As for the vertical louvers/West/summer scenario (figure 33) the results show that the maximum energy consumption in the later part of the day is very high, almost equal to the peak energy consumption which occurs in the early part of the day. Compared to the previously mentioned shading devices, the vertical louvers ranks in the last 2 effective one. The order is as follows (from most effective to least effective): horizontal louvers, horizontal overhangs, vertical louvers and finally vertical fins.

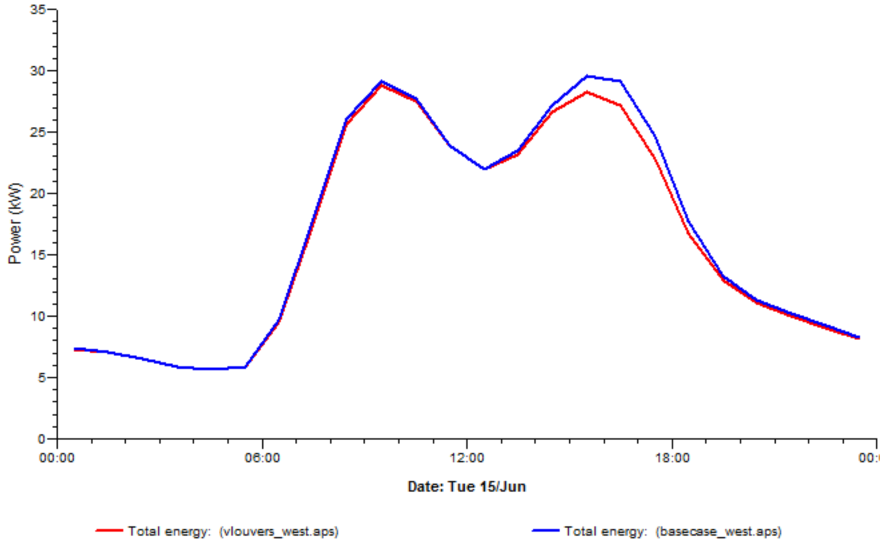


Figure 33 Graph showing energy consumption on 15th June in the vertical louvers/West/summer scenario (IES-VE)

In winter however (figure 34), the shading device performed more effectively, where as show in the figure, the energy consumption was the least during the later part of the day, indicating that the vertical louvers perform better in the winter than in the summer.

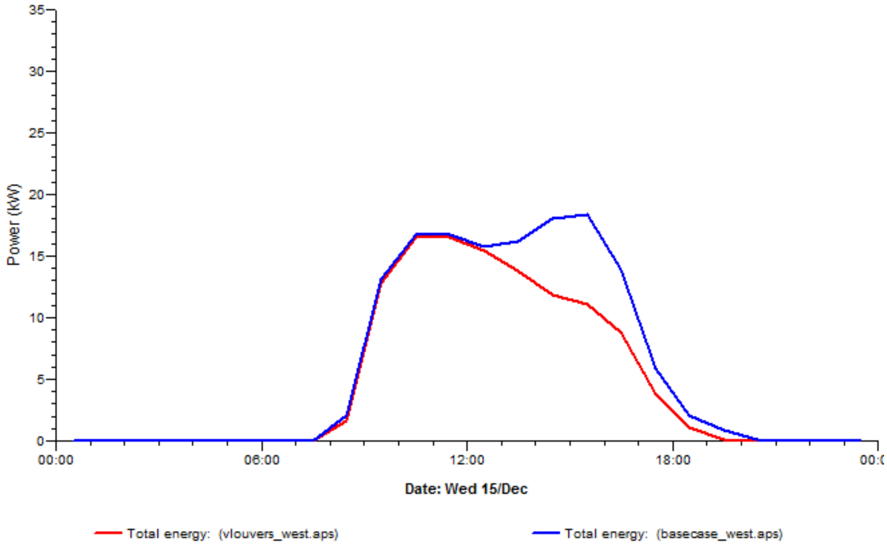


Figure 34 Graph showing energy consumption on 15th December in the vertical louvers/West/winter scenario (IES-VE)

c. East elevation

In the vertical louvers/East/summer scenario (figure 35), the results show that the vertical louvers performed better than the vertical fins, but less effectively than the horizontal louvers and overhangs. Compared to the West scenario, the vertical louvers were more effective on the East.

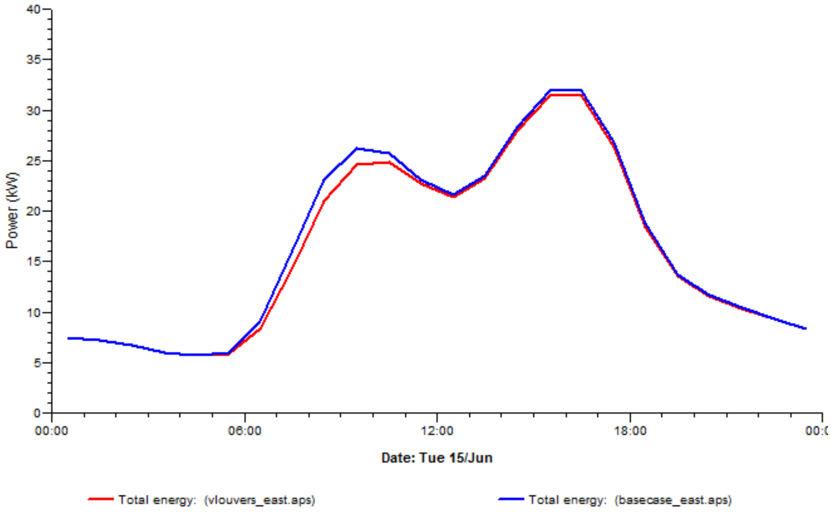


Figure 35 Graph showing energy consumption on 15th June in the vertical louvers/East/summer scenario (IES-VE)

The vertical louvers performed effectively in the winter (figure 36) where the lowest energy consumption of the day occurred in the early part of the day.

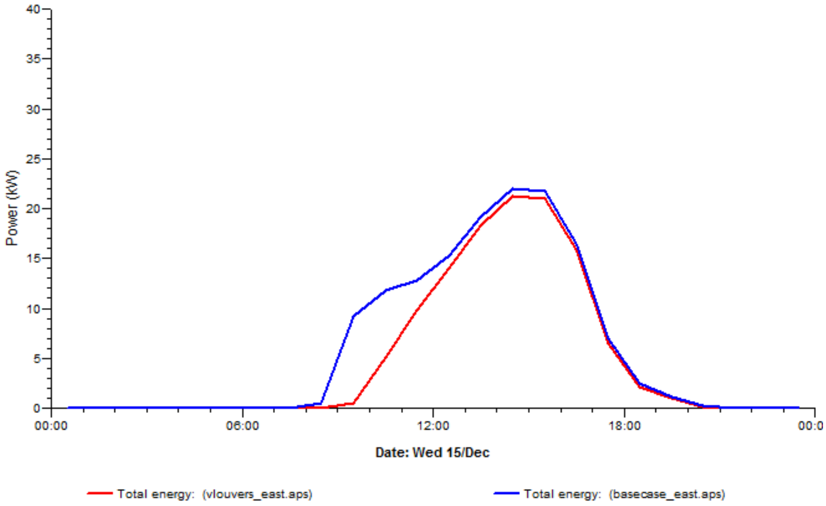


Figure 36 Graph showing energy consumption on 15th December in the vertical louvers/East/winter scenario (IES-VE)

d. Annual savings

Figures 37 show the difference in the annual energy consumption (MWh) when the vertical louvers were fixed on the three elevations, as well as the annual energy consumption of the base case.

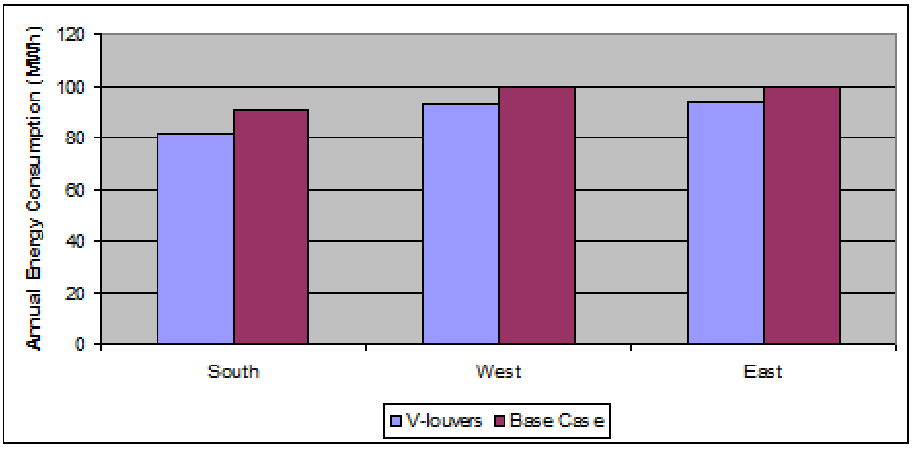


Figure 37 Bar chart showing the annual energy consumption (MWh) for the vertical louvers on the South, West and East orientations, and the base case

Similar to the previously discussed shading devices simulation, it is concluded that through the duration of a year, most energy savings were achieved when the vertical louvers are fixed on the South facade where the total energy savings was 10.54 % compared to the base case, which is second highest savings from all the previous shading devices. It also deduced that the vertical louvers perform similarly on both West and East facades where the percentage savings was almost 6% for both, which also ranks them as the second highest energy savings than all the previously discussed shading devices.

General discussion

Figure 40 shows the total annual energy savings percentage for all the simulated scenarios as compared to the base case.

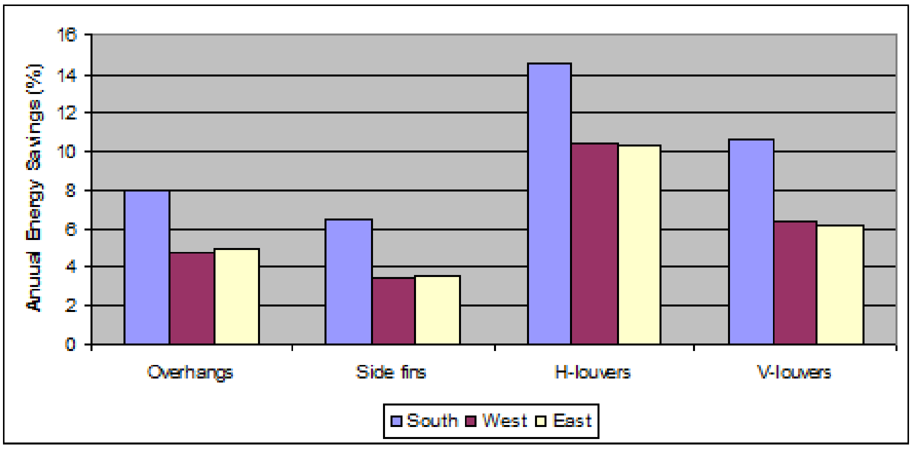


Figure 38 Bar chart showing the annual percentage energy savings achieved by the four shading devices on the South, West and East orientations

It is evident from Figure 38 that the ranking of the shading devices in term of effectiveness is as follows (from most effective to least effective): horizontal louvers, vertical louvers, overhangs and side fins. The louvers are expect to be more effective as their characteristics (number of slats, size, distance between slats) allow them to be more effective, where they cover a larger area of the window thus blocking more solar radiation, consequently lowering energy consumption.

All shading devices performed best on the South facade where the highest savings where achieved. This is consistent with existing literature (Hammad & Abu-Hijleh, 2010) and can be explained by the fact that the South facade has the longest exposure to direct sun radiation, thus having any shading device blocking the sun radiation will result in high savings.

The most effective device on all three elevations was found to be the horizontal louvers. It is noted that in previous studies that looked at shading devices in climates similar to that of Dubai, only horizontal louvers were used in the South and vertical louvers on the East and West facades Hammad & Abu-Hijleh, 2010 and Palmero-Marrero & Oliveira, 2010). There was no testing of horizontal shading on the East and West to be able to compare with vertical shading. This study shows that horizontal shading performs better than vertical shading on the East and West facades. It is important to emphasize here that the louvers were straight with no angle tilt, which can be deduced to have a great impact on the results.

Vertical shading was relatively less effective on the South, East and West elevations. This was consistent with previous studies that were performed for countries which have similar climates to that of Dubai; Brazil (Gutierrez & Labaki, 2007) and Malaysia (Al-Tamimi & Fadzil, 2011). This can be due to the inability of vertical louvers to effectively block solar radiation when they are not tilted. Without a tilt, they will only be able to block the solar radiation that is hitting the building from the sides, but will be ineffective when the sun is facing the facade, which is usually the case in all facades. This shows that vertical shading at all facades is not effective at 90 degrees. Thus it can be concluded that energy consumption rates can be lowered by changing the tilt of the shading, adding more fins/louvers as well as increasing their size (Ahmed, 2012) to reduce the uncovered area of the glazing.

Also, for all shading devices on different elevations, it was evident that the energy consumption decreased considerably in the winter rather than in the summer. This is expected since the day is shorter in the winter thus exposure to the sun is less. It can also indicate that the shading devices are more effective at blocking the solar radiation when the sun is at a lower altitude.

Optimum configuration

Based on the results discussed above, it is concluded that horizontal louvers perform best on all tested orientations. The optimum scenario simulated is the application of horizontal louvers on all facades. The annual energy consumption of the optimal case is reduced to 65.60 MWh while the base case is 97.90 MWh. The energy savings achieved by employing this configuration is 33%.

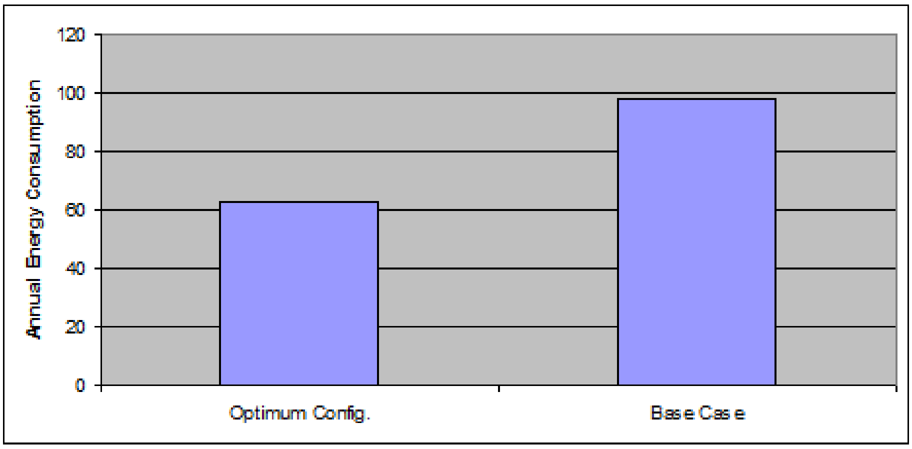


Figure 39 Bar chart showing annual energy consumption (MWh) of the base case and the optimal case

6. Conclusion and Recommendations

This study aimed to quantify potential energy savings achievable by adding shading devices to an office building in Dubai. Computer simulation was used – IES VE simulation tool- to calculate potential energy savings achieved by the use of four fixed external shading devices; horizontal overhangs, vertical fins, horizontal louvers and vertical louvers. The most basic application of these shading devices was applied where the shading devices were of common sizes as per existing literature and were fixed at 90 degrees angles with no tilts. The shading devices were simulated on the South, West and East facades.

The results show that all the shading devices perform effectively on the South facade. The most effective shading device on all the facades was found to be the horizontal louvers, where they resulted in 14.58% savings on the South and 10.3% on both the West and East facades. The optimum configuration found to be the application of horizontal louvers on all facades which resulted in energy savings of 33 %.

The louvers, both vertical and horizontal, caused higher savings which can be due to the fact that they covered a larger part of the window area in comparison to the other two shading devices. It is expected that higher energy savings can be achieved by variant configurations within each shading device, such as title angle and length of protrusion.

While this study was undertaken, a few gaps in the knowledge have been identified. This study attempted to contribute to one of the topics that was least researched in the region. Other potential research areas that were identified through the literature review or after obtaining the results of this study are explained below.

It was noted that very few papers addressed shading devices, in the region, or in climates that are similar to that of Dubai. Although some research was done on the field; Hammad &Abu-Hijleh (2010) investigated the potential savings of integrating dynamic louvers with automatic dimmers in an office building in Abu Dhabi through computer simulation. Palmero-Marrero & Oliveira (2010) also used computer simulation to check the effect of louvers on buildings in four cities, one of which is Cairo. Ebrahimpour & Maerefat (2011) looked at integrating overhangs with advanced glazed technologies in Iran. Ahmed (2012) investigated the effects of adding vertical shading devices on buildings in Egypt. While some of the countries in which these studies were done do have similar climates to that of Dubai, it is important that research is done exclusively for Dubai or the United Arab Emirates. This is because the design of an optimum shading device is a function of the Horizontal Shadow Angle (HSA) and Vertical Shadow Angle (VSA). These angles change with the solar azimuth and altitude, which change according to the latitudes and longitudes of a specific location. Hence, although studies from countries with similar climates can be used as references, results of higher accuracy and precision will be given by carrying out simulations for the latitudes and longitudes for Dubai. The importance of performing calculation specific to latitudes is repeatedly emphasized in the literature (Datta, 2001, Gutierrez & Labaki, 2007 and Tzempelika & Anthientis 2007). As explained earlier in this report, and proved later in the results, shading devices can result in substantial energy savings, consequently economic and emissions savings. Since designers in Dubai continue to design building with high window to wall ratios, it is imperative that shading devices are studied in more detail to integrate with these designs.

This study looked at the general application of four different types of shading, namely the horizontal overhangs, horizontal louvers, vertical fins and vertical louvers. General application refers to the characteristics of these shading devices that were tested where no optimal configuration of each device was selected. Configuration refers to the specific details of each shading devices, such as depth, slat thickness and distance between slats. All the devices in this study were fixed at a 90 degrees vertical or 90 degrees horizontal state and one configuration of each was tested. Through the literature, it was found that each shading device has an optimal configuration. For example, Hammad & Abu-Hijleh (2010) found that for the South orientation, the optimal angle of horizontal louvers was -20 degrees for shading devices in Abu Dhabi. It resulted in a total saving of 31.20% (Hammad & Abu-Hijleh, 2010). Although this result is not comparable to the results of this study in their study an automatic dimming technology was incorporated which could have caused the 10% increase in savings than the horizontal louvers tested in this study, which were not titled. However, it possible to conclude that each shading device has optimum configurations where small changes in the design of these shading devices can actually add significant savings at the same cost. Thus, it is recommended that further research in this area is done. Finding optimum configurations within each shading device and combining that with optimum orientation where maximum performance is achieved is estimated to achieve higher savings.

Another important point that came up in the research review is that the material of the shading device used influences its performance. Typical materials used include metal (solid and perforated), wood, glass (coated/tinted, fritted, sand blasted) and photovoltaic (Centre for Window and Cladding Technology, 2011). Gutierrez & Labaki (2007) found that using concrete shading devices caused a higher decrease in temperature inside the building than wooden shading devices. Based on this information, it is recommended that more research is done on the effect of various materials of shading devices on energy savings.

Also, in preparation for this study, a tour was taken around Dubai to investigate the existing shading devices that are already used. It was observed that the majority of the buildings had fully glazed facades or vast areas of glazing with no shading devices employed. Many of these buildings have been only recently built, which implies that they will be operated for at least another 20 years. Having these kinds of facade designs will cause a drastic increase in cooling loads to compensate for the heat gain through the windows. This calls for the need of investigating potential ways in which shading devices can be added to existing buildings. This would require a multi-disciplinary approach since the weight of the structure is crucial, thus structural engineers would need to contribute greatly. The design of very light weight shading devices designs can be proposed after the assessment of the structure of the existing building. Fortunately, with the advancements in materials technology, this can be made possible. Therefore, the investigation of adding lightweight shading devices to existing buildings is recommended.

It is worth noting that adding shading devices to a building influences many factors apart from the energy consumption, most importantly, the building users. Since windows are the prime source of daylight to occupants, it is crucial to take daylight penetration into consideration when designing shading devices. Also, shading devices affect both thermal (temperature) and visual comfort, especially for the area in the perimeter of the building. Shading devices should be implemented in such a way where the temperature indoors is reduced, glare is not occurring and the view to the outside is not blocked. It is recommended that these factors are covered in parallel with energy consumption as it is important to remember that the building is primarily built for it optimum use by the building occupants.

Finally, through the literature review part of this study, it was found that architects choose not to use shading devices because they are not aesthetically pleasing. The results of different questionnaires carried out on an international level highlighted that architects usually do not consider thermal comfort or solar gains when designing windows but rather cared about the appearance of the building (Menzies & Wherrett, 2005 and Kim et al, 2007). For the architects that did use shading devices, it was found that these devices were added to merely compliment the aesthetic of the building facades rather than shade the building, so no detailed shading calculations were made. Again, this study acknowledges the importance of the aesthetics of the building but in parallel, it highlights the importance of lowering energy consumption. Based on these findings, it is recommended that more research is to be done on aesthetics of shading devices. Literature lacked information on aesthetic and visual assessment. Roebig (2012) investigated the impact of visual assessment by combining onsite simulation, photomontage method as well as an aesthetic impact methodology. It was done to help planners assess the visual impact of their plans (Poebig, 2012). Gardner & Krishnamurti (2008) stated that aesthetics impact is one of the least comprehended and researched topic in architecture. In an attempt to fill that research void, they introduced a simulation software tool that formulates 3 dimensional geometrical structures based on aesthetic-derived algorithms. The development of the algorithms they generated was based on a comprehensive literature review on architectural aesthetics (Gardner & Krishnamurti, 2008). Based on these outcomes, it is recommended that architects undertake more research on aesthetics in architecture to find a way in which shading devices can be integrated in designs rather than choosing to eliminate their use completely.

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