# The energy saving potential of using the optimum external fixed louvers configurations in an Office Building in UAE climate condition


**By**

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## Abstract

Studies on the effect of external fixed louvers shading device on office buildings energy performance in UAE climate condition have shown that the louvers application caused a significant energy saving potential for the South, East and West orientations. However, the different louvers configurations and properties estimate a different performance in energy saving. This research aimed to exploring the influence of changing the louvers Aspect Ratio AR, louvers color, louvers slat tilt angles and louvers material in the energy performance of office building in Dubai city.

A virtual office unit model with the same parameters of existing office building in Dubai was used to evaluate the energy consumption performance of external fixed louvers for the South, North, East and West orientations. The IES-VE computer simulation software was used to predict the energy consumption in order to evaluate the effect of difference louvers configurations and properties in energy performance.

This study found that the louvers shade application with the same AR value of Louvers Width / Lovers Spacing distance (LW/LS) results approximately the same effect in energy saving. This is important as we can focus on the effect of AR only without having to test the different combination of LS and LW that give similar AR. The study found that the optimum energy saving reduction was recorded by using lovers (AR=3.0) with semitransparent material with Visible Transmittance (VT) 50% was achieved 33.16% annual average energy saving comparison with the base case (without louvers shading and light dimming system) for the South orientation. The optimum louvers AR configuration was AR=3.0 with annual average percentage of reduction in energy saving 29.33%, 25.06% and 23.47% for the South, East and West orientations, respectively. The study found also that the changing in louvers AR is more efficient in energy saving than the changing in louvers angles.

ترشيد إستهلاك الطاقة في المباني المكتبية بإستخدام أفضل الخصائص لعناصر (اللوفر) للتظليل الخارجي تحت تأثير مناخ دولة الأمارت العربية المتحدة.

تلخيص لمحتوى البحث.

أظهرت هذه الدراسة أن إستخدام عناصر (اللوفر) الثابته للتظليل مع نظام التحكم بشدت الضوء على كل من الواجهات الشرقيه، الجنوبيه و الغربيه في المباني المكتبية له الأثر الإيجابي الفعال في ترشيد إستهلاك الطاقه الكلية المستهلكة لهذا النوع من المباني. علاوة على ذلك أظهرت هذه الدراسة أن أداء وفعالية عناصر التظليل يختلف بإختلاف خصائص ومميزات هذه العناصر مثل (المقاسات النسبية لوحدات التظليل، معامل النفاذية للظوء، لون وحدات التظليل، زوايا شرائح وحدات التظليل ومواد هذه العناصر). يهدف هذا البحث العلمي إلى إختبار فعالية عدة خصائص لعناصر التظليل الخارجية (اللوفر) بهدف إستخلاص المواصفات والخصائص الأمثل في ترشيد إستهلاك الطاقه للمباني المكتبية في مناخ دولة الإمارات.

لتقييم فاعلية عناصر (اللوفر) في ترشيد إستهلاك الطاقة تمت التجارب على وحدة مكتبية إفتراضية لها نفس المواصفات من حيث مواد البناء المستخدمة والمقاست والتوجيه لمبنى مكتبي قائم في مدينة دبي (برج سابا المكتبي) في منطقة أبراج بحيرات جميرا. لمحاكاة العوامل المناخية لمناخ الأمارات مع المبنى الأفتراضي تم إستخدام برنامج المحاكا البيئي للبيئة الأفتراضية (IES-VE). تمت التجاربً على الأربع واجهات، الشمالية، الشرقية، الجنوبية والغربية منفردة.

أظهرت هذه الدراسة أن إسخدام عناصر التظليل الخارجية (اللوفر) بنفس المقاسات النسبية لوحدات التظليل (عرض وحدات اللوفر بالنسبة إلى المسافه بين الوحدات) له نفس الفاعلية في ترشيد إستهلاك الطاقه. أظهرت هذه الدراسة أيضاً أن أفضل الخصائص لعناصر اللوفر كانت بإستخدام المقاس النسبي ٣ إلى ١ أي عرض وحدات (اللوفر) يساوي ثلاث أضعاف المسافة بين وحدات التظليل مع ٥٠٪ معامل نفاذية للضوء بتوفير ٣٣.١٦٪ من الطاقه السنوية المستهلكه بالنسبة للوضع الأساسي للمبنى (أي بدون عناصر تظليل ونظام تحكم بشدت الضوء) للواجه الجنوبية. وأن أفضل مقاس نسبي لعناصر (اللوفا) هو ٣ بتوفير طاقه سنويه مقدارها ٢٩.٣٣٪ و ٢٥.٠٦٪ و ٢٣.٤٧٪ لكل من الواجهات الجنوبية الشرقيه و الغربية على التوالي.

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Also I offer my sincerest gratitude to my supervisor, Prof. Bassam Abu-Hijleh, who has supported me throughout my thesis with his patience and knowledge. I attribute the level of my Masters degree to his encouragement and effort and without him this thesis, too, would not have been completed. One simply could not wish for a better or friendlier supervisor. Deepest gratitude are also due to the members of the faculty of engineering, Dr. Abeer AlJanahi and Dr. Moshood Fadeyi who aided me In the various courses and workshops for many years.

Lastly, I offer my regards and blessings to all of those who supported me in any respect during the completion of thesis.

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# Chapter 1: General Introduction

## 1.1. Introduction:

The Green house gases are the main culprits of the global warming. These gases like carbon dioxide, methane, and nitrous oxide are playing hazards roles in the present times. These green house gases produced by buildings and cars trap heat in earth's atmosphere and thus result in increasing the temperature of earth which leads to natural disasters. Hammad and Abu-Hijleh, (2010) reported that 40% of the total world energy use is by buildings, whilst they (buildings) are responsible for roughly 70% of sulfur oxides and 50% of the carbon dioxide emission. 41% of the total energy consumed in the world was by buildings in Europe, mainly the commercial sector.

The intensity of solar radiation in a hot humid climate like Dubai is generally high throughout the year. The intensity of direct and diffuse radiation has a significant influence on the electric building performance, it influences the indoor thermal climate through direct solar heat gained through the glazing and indirectly through heat gain on a building's external surface. The full glazing facade in most contemporary office buildings does not help to improve this climate condition, in most cases it causes the problem of overheating, glare and the high cost in electricity for cooling the building which increases the green house gases emissions as a consequence. Several studies on solar control in a building's facade suggest that different applications of external and internal shading devices can create a significant improvement in the building's energy consumption.

The dramatic increase in the carbon dioxide emissions of the gulf region are due to the high consumption of energy used to cool buildings. Presently, emphasis should be placed on building technology to improve a new building's ability to deal with the climate in the most energy efficient way, especially focusing on the façade of the building, Aboulnaga, (2006) reported that the world energy agency in 2004 postulated the world's energy needs will increase 60% by 2030 and two thirds of this increase will come from developing countries.

The construction boom in The United Arab Emirates in the last decade has led investigators to research more about the environmental impact of a building. This would include testing in order to find the optimum facade solution to reduce energy consumption and provide the best internal environment in terms of human comfort. Furthermore there has been a huge increase in the amount of sulfur oxides and carbon dioxide emissions as a consequence of the building energy demand. The UAE was listed as the number two country in terms of carbon dioxide emissions, with 40% of the yearly electric loads come from the HVAC (Heating, Ventilation and Air Conditioning) equipment and up to 60% during the summer season. Figure.1.1 shows the growth in electricity consumption in UAE has increased 12 times from (5 to 75 billion KW/h) over the past 25 years as mentioned by the International Energy Agency (IEA) 2009.

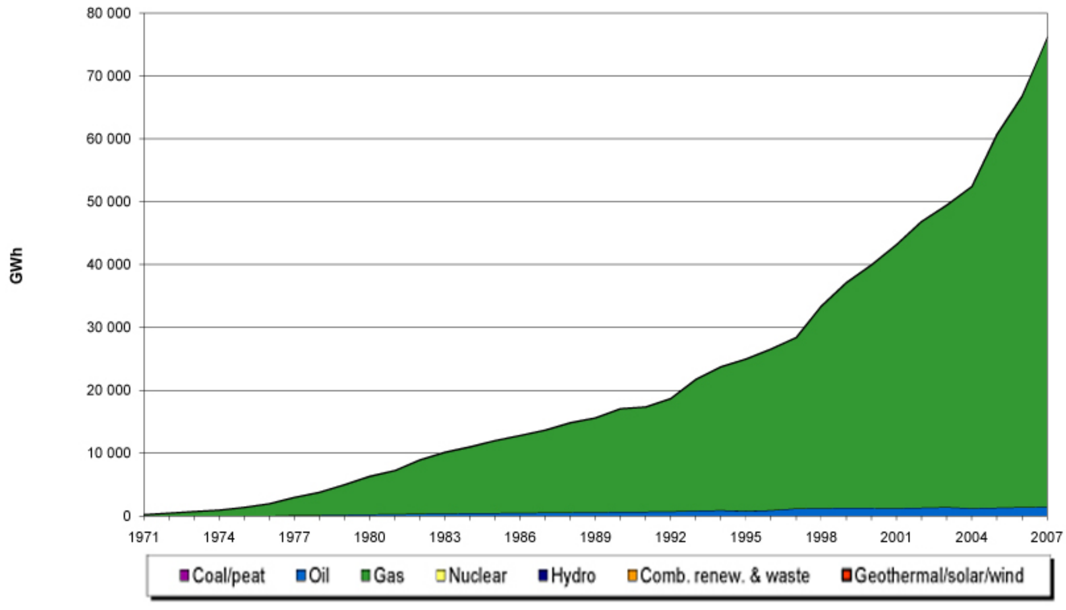



Figure.1.1. The growth in electricity generation in UAE from 1971 to 2007. (http://www.iea.org/stats/pdf_graphs/AEELEC.pdf).

The harsh, hot climate in this region increases the difficulties and the challenge of adapting the buildings environmentally especially in terms of cooling and lighting under the extreme solar radiation and the high temperatures. The exterior temperature in this region can exceed 50 degrees Celsius in the summer season which wastes a large amount of energy due to the increased cooling and lighting demands. In the UAE the rapid expansion of businesses illustrates the importance of improving the energy consumption of commercial buildings dramatically. The facades in office buildings have a very important role in terms of energy consumption. The amount of solar radiation penetrating the building through the glass exterior has a huge effect on the interior temperature which increases the need for air conditioning. From this point of view the designers must take into consideration these reasons carefully before starting to design the building façade in order to adapt the building to these harsh conditions. The possibility of controlling the penetration of daylight through the building skin could help to save a large amount of energy. Figure 1.2 shows that different sources of natural light can reach the building's interior in two ways, direct solar radiation and diffuse solar radiation. The American Institute of Architecture (AIA) (http://www.aia.org) defines optimum shading devices that could be used to provide a building with protection from direct solar radiation and allow diffused radiation to penetrate the building. By reducing the amount of light entering a building it would be possible to reduce the energy consumption of the building. Researchers studied the effect of different design solutions for the building's façade in order to find the optimum design strategy such as an external blind shading device, an interior blind shading device, overhang shading and different type of louver shading devices.

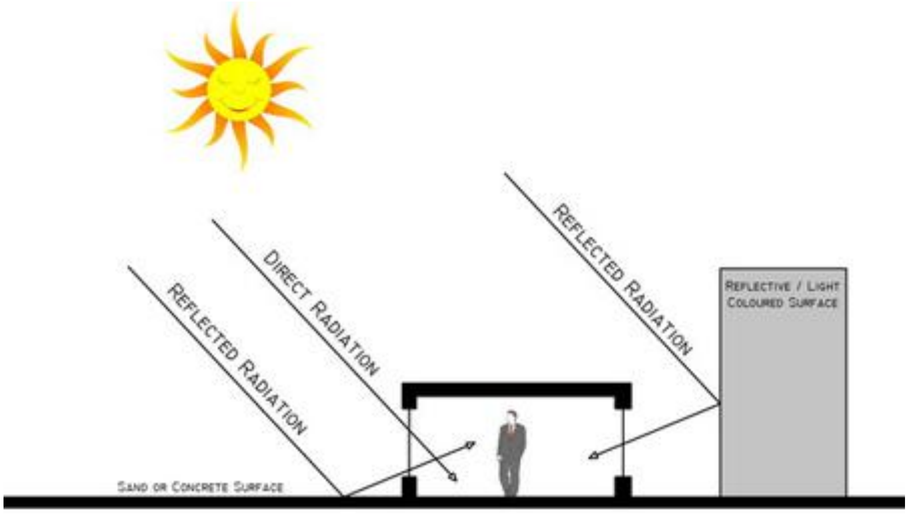



Figure.1.2. Natural daylight can reach the building interior by two main ways, direct solar radiation and diffuse solar radiation. (http://www.aia.org).

Using external louvers as a shading device in the building can help to reduce the negative effect of solar radiation by ensuring the maximum amount of daylight reaches the interior whilst minimizing heat transfer in order to reduce the total energy consumption of the building by minimizing the use of artificial light. Palmero-Marrero and Oliveira, (2009) studied the feasibility of using external louvers in order to provide a sufficient amount of luminance from natural sunlight and minimize the use of artificial light to reduce the electricity consumption and reduce the need for air conditioning by avoiding the overheating caused by solar radiation. The study found that the total power consumption could be reduced as a result of reducing the need for artificial lighting. On the other hand the use of some form of light reflector could enhance the interior visual comfort condition by avoiding glare and controlling the quality and the quantity of natural daylight from the different orientations. The main purpose of using this innovative shading system solution in a bright lighting condition is to avoid heat and glare, thus reducing the energy demand.

## 1.2. The building skin:

The basic premise of a building's skin is to differentiate between interior and exterior environments and to provide privacy, security and protection from the elements. Hammad and Abu-Hijleh (2010) identified the main functions of the building skin as the following:

- Protect the interior from physical environmental factors such as temperature, lighting, noise and inclement weather.
- Sometimes working as a structural support.
- Fire safety and security.
- Energy conservation.
- Aesthetics.

In modern buildings the facade structure is built up of different layers of materials such as glass, aluminum, concrete, steel and wood. These layers perform different functions such as weatherproofing, isolation and transparency which is considered as the main difference between old building facades and modern ones, however the Modern facade consists in most cases of more than 60% glass, reaching 80-90% in some cases. These facade surfaces are becoming thinner, lighter and smarter than the old facade technology. Figure.1.3. Shows the use of glazing material as a curtain wall in some modern buildings in Dubai.

Sutter et al, (2006) defined the importance of building skins in office building scenarios. The transparency between indoor and outdoor plays a very important role for healthy working environments by providing a good visual view and stable thermal comfort condition with the balance of quality and quantity of penetrated natural light. The penetration of natural light depends on the width, depth and height of windows, the type of glazing and the control element such as blinds, louvers or overhangs;

which has a direct effect on the building performance. Figure.1.4. Demonstrates the interaction between indoor and outdoor effected by building skin components.


Figure.1.3. Percentage glazing in the building facade of some famous buildings in Dubai city, UAE : (a) world trade center (40%), (b) national bank of Dubai (80%), (c) IPM building (80%), (d) Fairmont hotel (70%), (e) shangrila hotel (50%), (f) century tower (90%), (g) Chelsea tower (85%). (Aboulnaga, 2006).

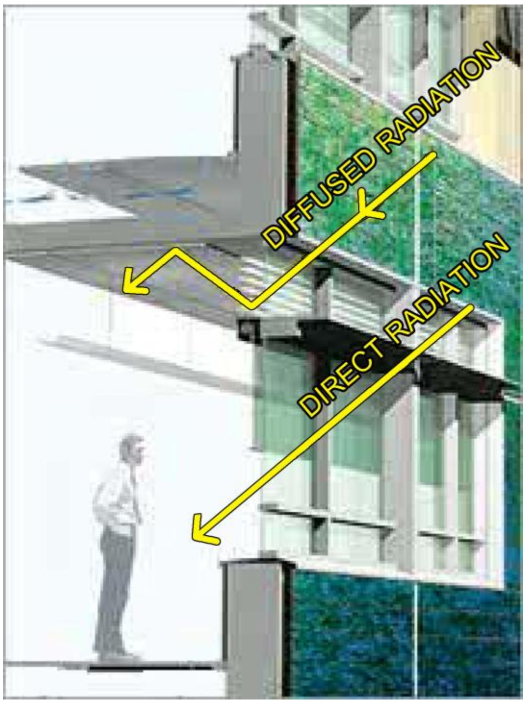



Figure.1.4. The interaction between indoor and outdoor affected by building skin components. (http://money.cnn.com/popups/2006/fortune/future_tower/8.html).

The facade color and material's properties also have a significant effect in building energy performance and visual comfort. Kuhn et al (2010) listed the main factors that affect the performance of transparent areas of building envelope as the following:

- The size of the glazed area.
- The orientation of the glazed area with respect to the sun.
- External obstructions from surrounding buildings or trees.
- The glazing properties.
- The properties of sun shading devices, and how they are operated.

Bessoudo et al (2010) said that the success of a building's envelope lies in maintaining the interior conditions without increasing the energy used. In this investigation the author considered the glass in a building facade as the most significant component of the building envelope in terms of human comfort and energy saving. However it must be said that comfort levels within a building can be altered by many different variables, including air temperature, air movement, humidity, a person's metabolic rate and the amount of clothing worn.

## 1.3. Office buildings energy efficiency:

The effects of environmental factors such as temperature, humidity, solar radiation, and air movement have a significant influence on a building's energy requirement. It can be concluded that excessive heat gain by solar radiation is one of the main environmental problems for buildings in hot humid climates. In most cases the solar radiation heat gain is extracted from the building by a mechanical HVAC system. The required cooling loads to maintain a comfortable internal environment combine with different factors to determine the amount of energy used in a particular building. The heat gain control is dependent on the rate and direction of the heat transfer across the building exterior. Office buildings are considered to have one of the highest energy consumption levels amongst buildings of this type. Juan, Gao, and Wang, (2009) estimated the annual energy consumption in office buildings varies between 100 to 1000 KW/h per square meter. This energy consumption value depends on location, office equipment, users, operation schedule, building envelope properties and the lighting system in use. Juan, Gao, and Wang, (2009) mentioned that in the US 70% of the total energy consumed is for HVAC and lighting in office buildings with rates in the UK at 72%.

### 1.3.1. Energy efficiency and solar radiation:

Solar radiation and natural daylight are the main factors affecting the building's energy performance by controlling the thermal comfort, visual comfort and energy demand. However increasing the daylight, efficiency results in lower lighting electric and cooling demand (HVAC) electric load. Li and Wong (2007) illustrates the effect of optimum daylight design solution for the lighting and cooling electric demand in the office buildings reach 70% of the total electricity consumption. In addition to this the cooling demand is reduced when reducing the lighting generated heat gain.

Li and Tsang (2008) demonstrated the main design principle that the designer should consider before starting to design buildings with high daylight efficiency as the following:

- Facade glass type: the glass shading coefficient value controlling the amount and quality of the daylight penetrating inside the building.
- Windows area: window size and shape have a significant effect on the daylight efficiency; their study showed that the window size should not be less than 1/10 of the indoor space area to provide enough daylight for the whole space.
- Shading devices: shading devices help to avoid overheating by protecting the opening from the direct solar radiation and allow the diffused light to penetrate inside the building to enhance the natural light.
- Leas span: the leas span is the floor plan depth to floor height ratio, which has a significant effect on the indoor luminance uniformity.
- External obstruction: External obstructions influence the natural daylight by two main factors, the amount of the sky being obstructed or unobstructed and the color of the neighboring buildings.

### 1.3.2. Energy performance:

Piper, (1999) cited in Chung and Hui, (2009) listed six main factors that influence the energy use performance in buildings. These factors are the people factors like occupants or indoor temperature set point, building type, occupancy factors, climate factors, building age factor, and energy end use system factor like office equipment or lighting control. Kofoworola and Gheawala (2009) investigated the life cycle energy assessment of a typical office building, The study has shown that simple energy efficiency and low cost energy demand were measured by using some design strategy like applying set point temperature close to the standard indoor room of 26°, applying shading devices, using appropriately sized windows, employing glazing with lower heat transfer coefficient and low solar heat gain coefficient. This design technique may reduce the energy consumption of office buildings during the operation time.

## 1.4. Dubai office buildings scenario:

The scale of office buildings in Dubai varies in size and complexity from big headquarters to small office buildings of different business types. Because of the high temperature and humidity here, full HVAC systems become the most common mechanism for residential and commercial buildings.  Al Sallal and Ahmed, (2007) noticed that 2200 Kwh/m2 is the amount of yearly solar radiation in UAE and the direct falling illumination can exceed 90000 lux in summer with 50° temperature which is considered as the second highest level in the world. On the other hand some common design practices and building component such as inadequate building form, shading devices, large area of glass windows or glass curtain wall. Expose the building to strong solar radiation and high temperature making the cost of cooling buildings high. In 2003, Dubai municipality started to implement the building energy consumption regulation by enforcing Decree 66 which includes saving requirement, mainly insulation and glazing properties. In 2008 the ruler of Dubai issued a new decree implementing green buildings specification and standard in Dubai. However, the fast progress of business in Dubai has improved the energy consumption of commercial buildings dramatically.

As has been mentioned by Dubai Statistics Centre that 39 high rise office buildings (purely commercial buildings) were built in Dubai from the period 1979 to 2010, however several mixed used buildings are not included in these statistics. This dissertation presents a general analysis for these 39 office buildings in Dubai in order to investigate the design characteristic for these existing buildings. The main aim of this analysis is to categorize all current modern office buildings in Dubai from 1979 to 2010 to illustrate the basic building features which would effect on interior lighting comfort, heating and cooling loads such as facade orientation, facade materials, external shading devices used and building height. Some important facade features are not included in this analysis such as internal glass height, glass type, and shading coefficient value for the glass. Figure 1.5 shows the 39 office buildings pictures numbers of from 1 to 39. Table 1.1 shows the building features in terms of building name, build year, number of floors, façade materials, glazing orientation from east west and south, and external shading devices used.


Figure.1.5. Office buildings built in Dubai in the period from 1979 to 2010 with listed numbers from 1 to 39. (Mix of personal archive 9/2010 and google earth photos).

Table 1.1. Dubai office buildings categorization by buildings name, build year, number of floors, facade materials, glazing orientations and external shading.

| z | Tower name | Year | Floors | Façade materials | | Façade glazing orientation | | | External shading devices | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Glass | Other | East | West | South | None | Poor | Exist |
| 01 | Al Salam tecom tower | 2006 | 46 | 55% | 45% | X | - | X | X | - | - |
| 02 | Dubai chamber tower | 1995 | 18 | 98% | 2% | X | X | X | X | - | - |
| 03 | Etisalat tower | 1992 | 17 | *65% | *35% | X | X | - | X | - | - |
| 04 | Arbift tower | 1982 | 23 | *40% | *60% | X | X | X | - | X | - |
| 05 | ARY digital tower | 2007 | 45 | 80% | 20% | X | X | X | X | - | - |
| 06 | Almas tower | 2008 | 65 | 75% | 25% | X | X | X | X | - | - |
| 07 | Emirate telecom tower | 2006 | 33 | 55% | 45% | X | X | X | - | - | X |
| 08 | Crowne plaza offices | 1994 | 22 | 85% | 15% | X | X | X | X | - | - |
| 09 | Buhaleebah Tower | 2005 | 28 | 80% | 20% | X | X | X | X | - | - |
| 10 | Dubai Islamic bank tower | 2005 | 13 | 95% | 5% | X | X | X | X | - | - |
| 11 | Bur juman office tower | 2005 | 28 | 90% | 10% | X | X | X | - | - | X |
| 12 | Al Moosa office tower | 2001 | 30 | 95% | 5% | X | X | X | X | - | - |
| 13 | Index tower | 2008 | 80 | 78% | 23% | X | - | X | - | - | X |
| 14 | Capital tower | 2006 | 40 | 88% | 12% | X | X | X | X | - | - |
| 15 | Al thuraya tower | 2006 | 30 | 62% | 38% | X | X | X | X | - | - |
| 16 | The gate tower | 2004 | 15 | 65% | 35% | - | X | X | X | - | - |
| 17 | Shatha tower | 2006 | 40 | 85% | 15% | X | X | X | X | - | - |
| 18 | City tower | 1997 | 16 | 90% | 10% | X | X | X | X | - | - |
| 19 | Fortune tower | 2006 | 35 | 97% | 6% | X | X | X | X | - | - |
| 20 | Bank Iran tower | 2005 | 11 | 75% | 25% | - | X | X | X | - | - |
| 21 | Al rustamani office tower | 2005 | 15 | *77% | *23% | X | X | X | X | - | - |
| 22 | Convention tower | 2003 | 14 | 65% | 35% | X | X | X | X | - | - |
| 23 | Green building tower | 1999 | 17 | 90% | 10% | X | X | X | X | - | - |
| 24 | Al Reem tower | 1995 | 25 | 45% | 55% | X | X | X | X | - | - |
| 25 | NBD tower | 1998 | 20 | 80% | 20% | X | - | X | X | - | - |
| 26 | AU gold tower | 2007 | 35 | 90% | 10% | X | X | X | X | - | - |
| 27 | Al Attar tower | 1999 | 18 | 90% | 10% | X | X | X | X | - | - |
| 28 | Al Naboodah Tower | 1999 | 17 | 85% | 15% | X | X | - | X | - | - |
| 29 | Twin tower 1&2 | 1998 | 22 | 80% | 20% | X | X | X | X | - | - |
| 30 | Emirates headquarter | 2006 | 9 | *85% | *15% | X | X | X | X | - | - |
| 31 | Pacific tower | 2006 | 40 | 80% | 20% | - | X | X | - | X | - |
| 32 | Dubai world trade center | 1979 | 39 | 40% | 60% | X | X | X | - | - | X |
| 33 | Emirates tower | 2000 | 54 | *80% | *20% | X | X | X | - | X | - |
| 34 | Oud Metha offices | 2000 | 17 | 75% | 25% | X | X | X | X | - | - |
| 35 | Saba tower | 2006 | 35 | 70% | 30% | X | X | X | - | X | - |
| 36 | One lake plaza tower | 2007 | 40 | 85% | 15% | X | X | X | X | - | - |
| 37 | Silicon Oasis offices | 2006 | 15 | *80% | *20% | X | X | X | X | - | - |
| 38 | Indigo Tower | 2007 | 35 | 65% | 35% | - | X | X | - | X | - |
| 39 | Business avenue building | 2000 | 11 | 95% | 5% | X | X | X | - | X | - |

(*) Estimated by the author. (No external reference available).

Analyzing the data in table 1.1 the following conclusions and graph could be drawn:

- Only 10% of these buildings did NOT use effective external shading devices and 17.5% with poor shading devices implementation, deep recessed window or overhang.
- 93% of these office buildings use 50% of the building facade as a glass curtain wall.
- 80% of these office buildings were oriented east, west and south with full glazed facades.

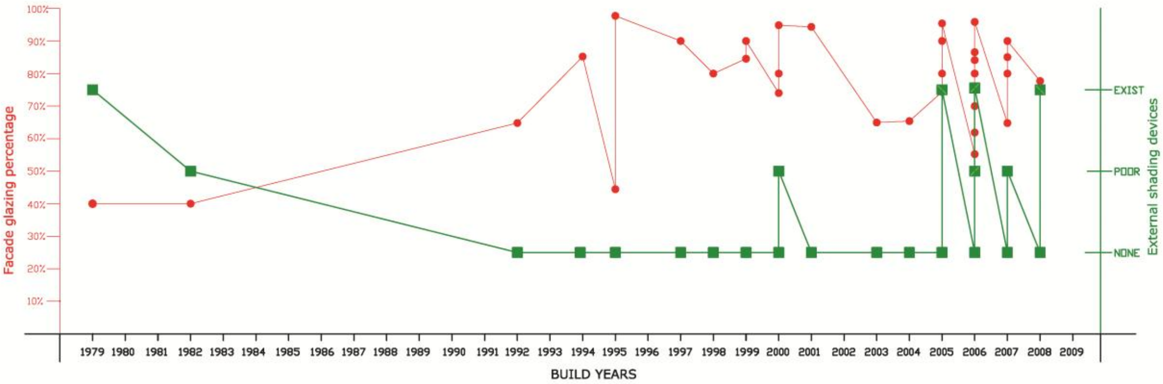



Figure.1.6. The using of external shading and glazing façade in office buildings during the periods from 1979 to 2010.

Figure 1.6 presents a lack of environmental design consideration which results in significant energy waste from the buildings. However there is no relevant building regulation referring to indoor luminance level, shading devices, glass type or building oriented for commercial building in Dubai.

Initially in Dubai, there are no building regulations which address daylight energy conservation or energy efficient building in terms of daylight and thermal performance. The regulations are improving gradually, due to the recent increase in the popularity of ‘green’ designed buildings.

# Chapter 2: Literature review.

## 2.1. Introduction:

Solar radiation influences the building internal climate by directly heating the space through glazed windows and indirectly by heating the external envelop of the building. In the case of glazed windows or glazed curtain walls, almost all of heat radiation passes directly through the glass into the interior space where it becomes trapped by the greenhouse effect. These effects become a real problem if the glass is completely unprotected and exposed to direct solar radiation. The heat that is absorbed by the external envelops of the building also increases the surface temperature and induce conduction in to the internal space. In general solar shading devices are designed in order to exclude the unwanted direct solar penetration by protecting the exposed windows area of the building envelop and allow the diffused solar radiation in order to enhance the interior environment. Several studies have been under taken to test the energy saving effect of shading systems and the interior visual comfort in different areas. This review focuses on the studies related to the influence of shading devices on building energy performance and visual comfort.

## 2.2. Shading device applications:

There are many types of shading device applications available and their choices are depend on the requirement of each environmental condition. However there are three main common categories of shading devices for controlling the amount of solar radiation penetration through the building skin.

### 2.2.1. Natural shading devices:

The application of natural shading devices is referred to as the sensitive manner of shading buildings without altering the physical aspect such as trees or vegetation and building orientation. However trees and vegetation have a significant role to play in shading a building facade especially in hot climate regions. Lam and Miller, (2007) reported that the shading performance of trees and vertical living plant canopy plays a major role in reducing summer overheating and are considered to be a bioclimatic design strategy. Moreover, the use of living plants in a certain way helps enhance the thermal effect and the air quality. Also, putting a living plant within the cavity of double glazing windows may reduce the excessive solar radiation during the summer season which enhances the indoor thermal comfort and helps reduce the cooling load in order to save energy. Lam and Miller, (2007) research investigated the effect of the vertical deciduous climbing plants canopy shading performance in an existing building that was monitored for two years, as illustrated in figure 2.1. This study investigated the importance of the bio-shading effects which helped to avoid the urban heat island effect and was able to enhance the surrounding environment of the building. Moreover, the performance of the bio-shading improved the dynamic thermal comfort. But the main problem of this study was the shortage of existing methodologies and measurements techniques to estimate the bio-shading performance.


Figure.2.1. Vertical climbing plants canopy shading windows. (Lam and Miller, 2007).

The American Institute of Architecture (AIA) (http://www.aia.org) found that the natural environment can be used to shade the opining in low rise building. Deciduous trees can effectively shade the façade when avoidance is desired, and permit solar penetration where passive solar gain is sought. Vegetative shade also works well in all seasons. However in summer the trees can transmit as low as 20% from the solar radiation. Figure 2.2. Shows the vegetation shading effect in buildings.

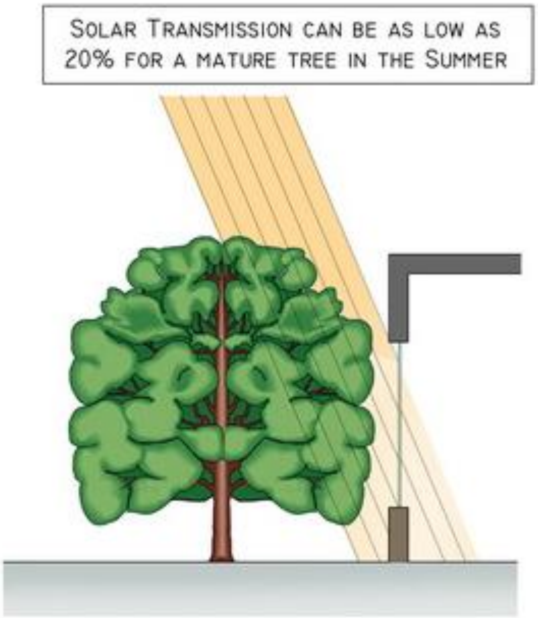



Figure.2.2. Vegetation shading effect on a building. (http://www.aia.org).

### 2.2.2. Internal shading devices:

The application of internal shading devices refers to the use of shading elements internally. Different types of internal shading devices are commonly used; such as Vientiane blinds, entrant louvers, curtain etc. Different studies have tested the performance of these internal shades.

Bessoudo et al, (2010) investigated the indoor thermal environment of a fully glazed facade office building with different types of internal shading devices under varying climate conditions in the winter season. This investigation illustrated the performance of using roller blind shade on clear winter days. The study showed the indoor thermal environment improved with the use of this type of shading. The use of Venetian blinds in similar climate condition, helped to enhance the indoor comfort thermal condition, assuming a certain tilt angle of the slats. Specifically, maintaining a horizontal position with tilt angle zero degree can still cause discomfort on the indoor space. On the other hand horizontal slat tilt angle with 45 degree has a significant effect on indoor thermal comfort. In addition to the facade orientation, building latitude and facade materials have a big role in this term.

The interior shading devices used on a south facing façade with large window area has a significant effect on improving the interior thermal comfort for all window type except the double glazed reflected window type. This highlights the relationship between the windows type, glass properties and the shading devices performance, (Carmody et al, 2004 cited in Bessoudo et al, 2010).

Kang et al (2010) investigated the effect of thermal comfort control when using internal shading with regard to the energy saving potential in office buildings. This study indicated that thermal comfort control provides consistent thermal comfort and significant energy saving effect. In addition to this the study showed the change of the facade glass properties in order to control the indoor space thermal comfort could enhance the energy performance.

Koo, Yeo and Kim (2010) proposed a new control method to control the automated Venetian blinds shading to maximize the benefit of daylight, avoid glare and to reduce the electricity consumption for lighting and heating energy. The new control method concept aim to protect occupant from direct sunlight and adjust their positions such as the lower end of the blind and the slat angles according to the hourly outdoor solar position and predetermined control reference depth from a window in order to keep the outside view possible all the times with the consideration of office room size and occupants number and position from the windows. This investigation studied the solar azimuth angle on a horizontal plan view as figure 2.3 and the solar altitude angle on a vertical section view as figure 2.4 in order to find the best control strategy for Venetian blinds.

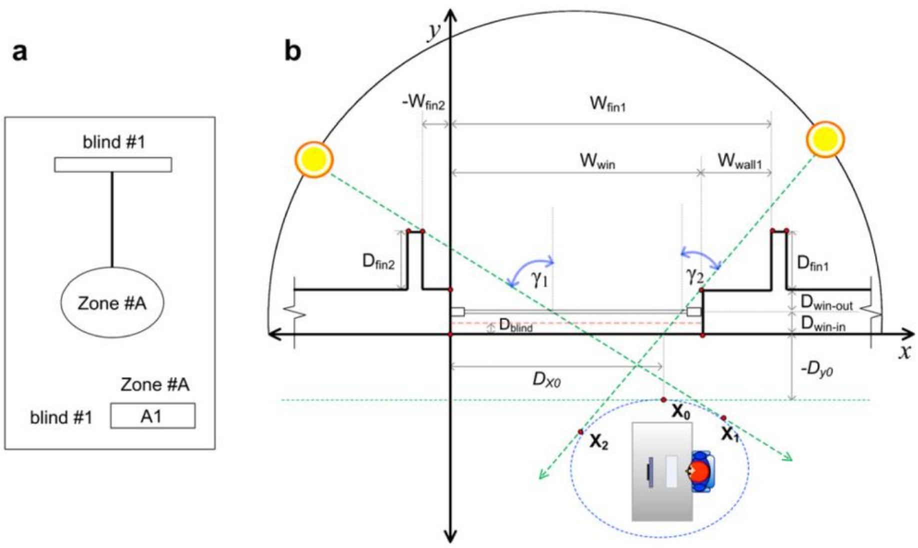



Figure.2.3. Azimuth sun angle analysis with Venetian blind and occupant position, (a) control method for one blind with one controlled zone, (b) minimum and maximum surface solar azimuth angle in horizontal plan. (Koo, Yeo and Kim, 2010).

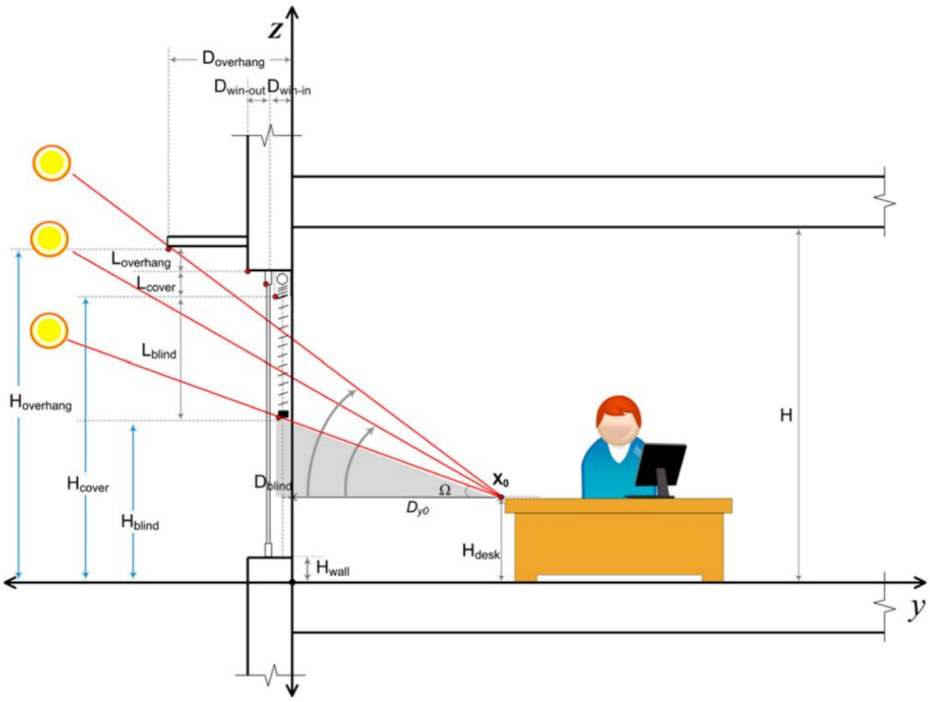



Figure.2.4. Latitude sun angle present the lower end of blind to block direct sunlight beyond the depth. (Koo, Yeo and Kim, 2010).

This study resulted in a new method for blind control with maximum diffused daylight, full protection from direct sunlight and glare, for the studied cases.

It's very important to understand the different criteria which have direct and indirect effects to improve the office work environment. From this point of view Sutter et al (2006) focused on investigating visual and thermal comfort conditions by controlling the quantity and quality of the natural daylight from one orientation only. With the internal shading system, the blind shading system, the worker can enhance the interior environment. This experimental study investigated the user's behavior and the physical parameters of daylight in eight offices with the same orientation. This field study resulted in developing a controlled algorithm for using blinds and observed that some users were relatively consistent with their behavior when related to the visual environment in their offices.

### 2.2.3. Exterior shading devices:

For the purpose of this thesis, the application of fixed external louvers shading device will be the main concern. The application of external shading devices refers to the use of shading element on the outer part of the windows area in general these devices can be either movable or fixed. The design of the movable external shading devices does not affect shading devices efficiency as they always can be turned so as to cut off the sun’s rays; their efficiency is variable and depends on their position. On the other hand the design of fixed external shading devices has to exclude the sun rays from penetrating radiation through the shading. They can’t be adjusted according to the orientation of sun position. The effectiveness of a fixed shading device depends on its orientation, sun position in the sky and the device properties. In addition the success of  fixed shading devices has to be designed and located in such a way that while eliminating solar penetration and it should not adversely reduce the internal luminance in all the year seasons. Figure 2.5. Illustrate the ideal basic shading strategy in different seasons.

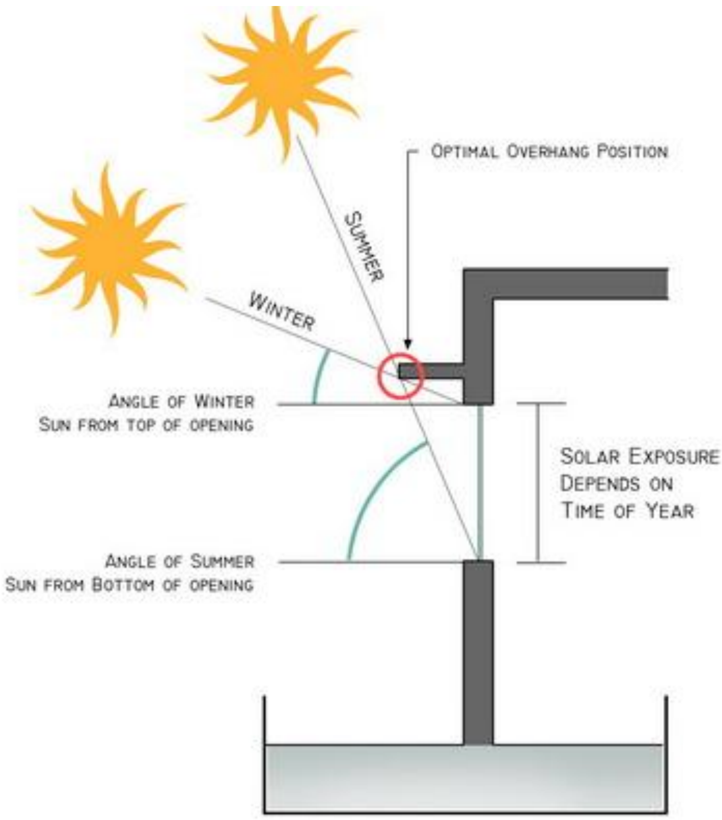



Figure.2.5. Ideal basic shading strategy for external fixed shading device in deferent seasons. (http://www.aia.org).

Hammad and Abu-Hijleh (2010) explored the energy saving potential of using dynamic external louvers shading system with the light dimming strategy in an office building in Abu Dhabi. The main goal of this study was to investigate the optimum angel of the dynamic louver shading system in office buildings for the south, east and west façades in terms of energy saving by reduce the cooling energy consumption and the lighting electric demand. This saving in energy happened as a consequence of taking the maximum benefit from the natural sun light and at the same time avoid the negative effect of the direct solar radiation like the overheat gain and glare. This investigation resulted that the energy saving value of using the light dimming strategy only from the south façade reached 24.4%, 24.5% from the east façade and 25.19% from the west façade. In contrast by applying the dynamic louvers shading system with the light dimming strategy, the building energy saving reached 34.02% from the south, 28.57% from the east and 30.31% from the west orientation. Moreover this study shows the optimum louvers angle for the different orientation in terms of energy saving, for the south horizontal louver the optimum angel -20 degree and for the east and west vertical louvers -20 degree to have the maximum energy saving. Figure 2.6. Shows the different louvers angles were tested by Hammad and Abu-Hijleh (2010). In this study the researcher used a horizontal louvers in the south façade while vertical louvers are used in both east and west façade refer to the louvers configuration based on the daylight guidelines provided the building technologies department at the Lawrence Berkeley National Laboratory. Offices that accommodate medium density occupancy were modeled to this test. Two work station with tow computers of 370 (w) and two workers with maximum sensible gain 90.0 W/ person. The HVAC system was worked continuously to maintain the interior temperature of 24° with room infiltration rate 0.25 air changes per hour. Lighting system was designed to work all the weekly working days from 07:00 am to 07:00 pm to provide, in addition to the natural daylight, internal luminance level of 500 Lux based on IESNA standard.  The main variables studied in order to test louvers performance were the following:

- Position of lighting sensor, the researcher test the lighting sensor performance in tow distance from the window 2 meter and for meter passed in ceiling level.
- Two glass shading coefficient were used in this test, 0.41 and 0.746.
- Slat tilt angle of louvers.
- Building orientation.

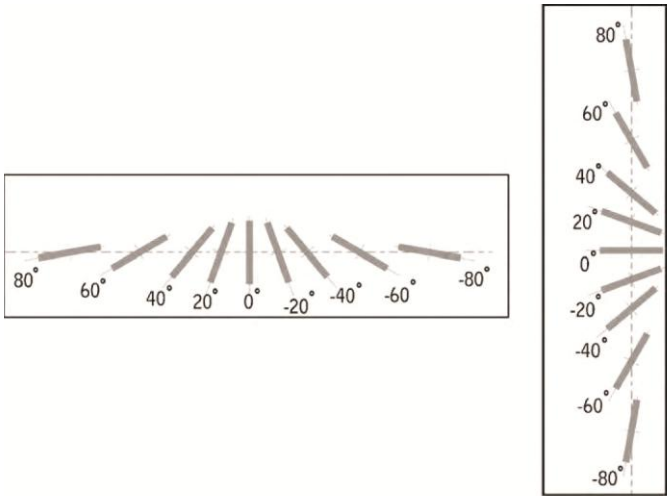



Figure 2.6. Different louvers angles were tested in this thesis. (Hammad and Abu-Hijleh, 2010)

Colline et al (2007) found that the use of the external rotatable louvers shading system in the building façade had a significant efficient in energy saving with the consideration of the louvers materials, louvers angel, louvers position and the glass properties. James and Bahaj (2004) studied different façade solutions for office buildings in order to provide a comfortable working environment by avoiding the negative impact of the solar radiation; solar glare and excess overheating by reduce the heat gain. There study investigates the efficiency of different solar gain control options to reduce the overheating and to avoid glare at the same time in office buildings. The possibility to control solar gain problem by different design solutions such as window film, fixed external louvers and smart glazing solution. However the researcher identified the possibility façade solutions to three different distinct types first the mechanical solution such as the air conditioning system and the forced air convection but the disadvantages of this type of solutions the higher cost, consume a large amount of electric, and the significant environmental impact. Second the glazing solutions like window film, E-chromic glazing or Holographic Optical Elements (HOE) system these types of façade strategy provide a sustainable solution but it has a limited performance in some cases and some conditions. Third the shading device system such as fixed louvers shading system and the external motorized blinds, these innovative façade solutions in some optimum way help to reduce the building energy demand and provide a healthy environment solution. Figure 2.7 shows the three façade solutions.

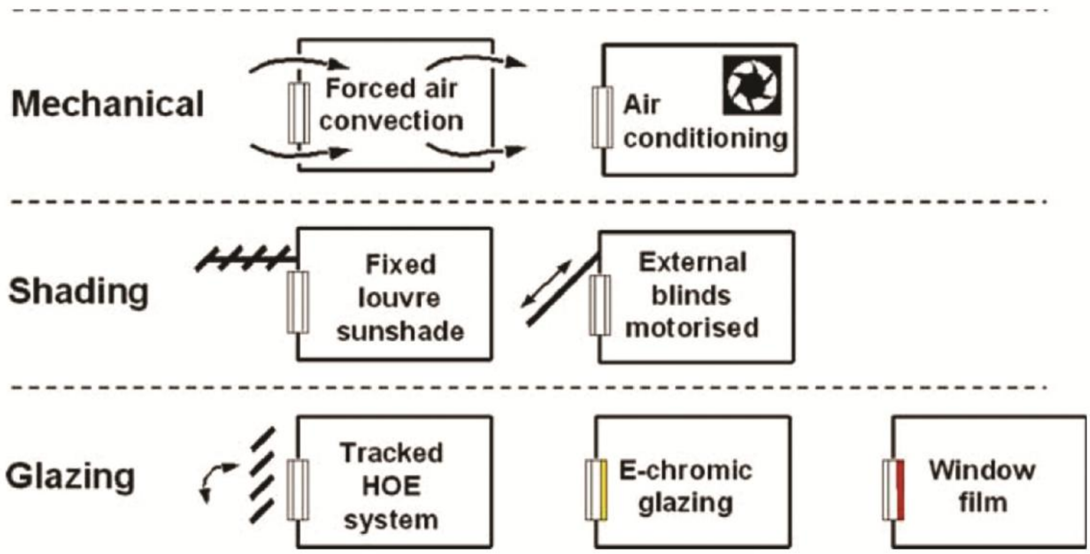



Figure 2.7. The three main solutions studied by James and Bahaj (2004).

James and Bahaj (2004) found that the horizontal fixed louvers above the window reflect the direct solar radiation away from the window glass which avoid glare effect and at the same time allowing the diffuse light to penetrate inside the interior space with 500 lx luminance in minimum to reduce the need of the artificial light, however the relationship between the louvers blade and the sun azimuth. Moreover the horizontal fixed louvers system allows maintaining the full window view which considered as an important point for the healthy working environment.

Palmero- Marrero and Oliveira (2009) mentioned that the louvers shading system allowed the air to penetrate through the glass and the shading component to absorb the solar heat gain. This effect on the fully shaded façade could reduce the solar heat gain by around 80%. The louvers shading system simulation test shows that using of louvers shading in building façade help to provide an indoor thermal comfort and it has a significant energy saving in terms of cooling energy load. This studies used horizontal louvers (overhang type) for the south façade and horizontal louvers with vertical layout for the east and west façade. Initially the simulation used one building form with a floor area of 120 square meters with four facades. Large windows in the south façade and smaller ones in east and west facades. All the windows had double glazing glass with a U-value of 3.21 m/m2K and a g-value of 0.72 m/m2K. The simulation for all the regions used the same building geometry. The louvers in the south façade were placed as horizontal overhangs while those in the east and west facades were fixed in front of the windows and parallel to the façade. Figure 2.8 shows model geometry and the louvers installation in different facade. The relationship between the height of the windows and the width of the louvers was considered. The louvers were made of aluminum sheets each 0.25m wide. Other input data were also considered like the infiltration rate, which were 0.6 air changes per hour, internal gain of four persons and an artificial lighting of 5w/square meters. The occupants were present from 8am to 6pm with the exception of weekends. The building cooling loads for the indoor temperature ranged between 25-20 degrees for all seasons. Finally the simulation was extended throughout the whole year, from November to April for cool season and May to October for hot season. The result shows also the performance energy saving of the louvers shading effect depend on the location conditions, louvers inclination angle, the window, number of louvers, spacing between louvers, position above the window, and louvers area. All these parameters had a significant effect to increase the performance of energy saving.

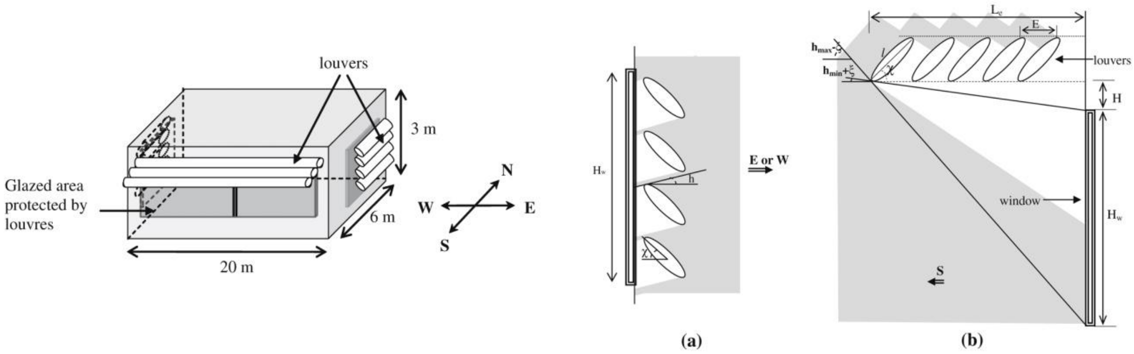



Fig.2.8. Model geometry and the louvers installation in different facades (a) East and West louvers installation, (b) South louvers installation. (Palmero-Marrero et al 2009).

Baldinelli (2008) investigated the performance of office building energy for the double skin façade with a movable integrated shading system. This study shows a good energy performance of this system for the both seasons in summer and winter with the comparative the building façade without movable shading system as a consequence of overheating. The simulation energy analysis illustrated the importance of the shading component material properties; however the high reflective shading device has a significant effect in summer season by avoiding extremely heat gain and to enhance the interior space in winter. The simulation result showed also the exterior thermal performance of this movable shading system in three different louvers configuration closed natural convection, open natural convection and forced convection had a significant thermal effect especially in summer by allowing the cool air to penetrate through the air gab between the shading component and the glass skin which led to absorb the heat gain from the building body as shown in figure 2.9. On the other hand the positive thermal performance of this shading system in winter by closed the shading component. Moreover the result showed the amount of saving energy for the double skin façade with integrated movable shading system up to 60 kWh per year per façade square meter when comparing this test with classic façade system with fully glazing or with opaque wall façade.

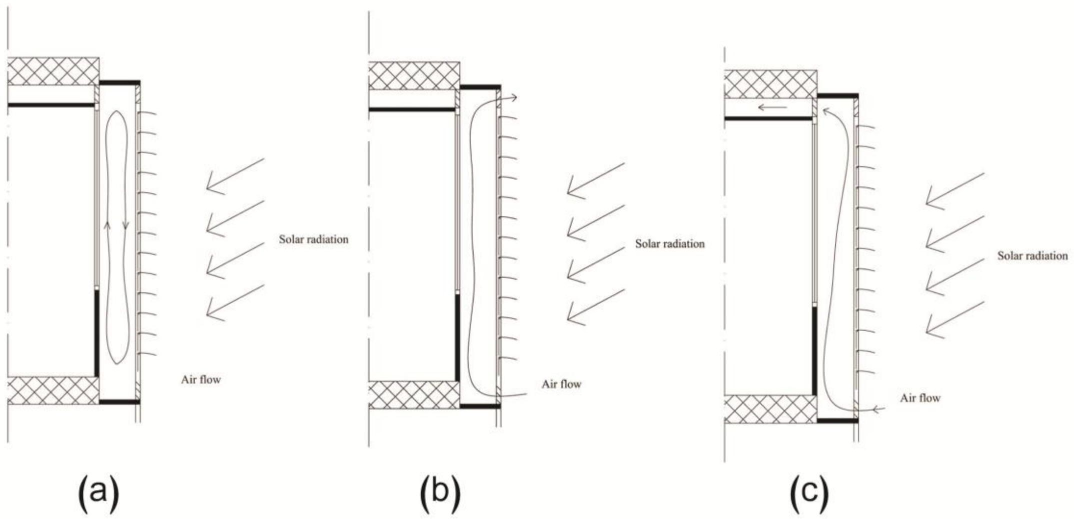



Fig.2.9. Movable shading system in three configurations as a thermal solution in hot season, (a) closed natural conviction, (b) open natural conviction, (c) forced conviction. (Baldinelli, 2008).

Freewan et al (2008) studied the interaction between external louvers and the interior components like the ceiling geometry to increase the role of this shading system in terms of natural lighting. However the building energy cold reduced as a consequence of modifying the louvers parameters and ceiling geometry by taking the maximum benefit from the natural daylight in order to reduce the artificial light electric demand and at the same time to avoid the artificial light heat produced. The experimental study showed the significant performance effect of louvers by modifying the ceiling geometry in terms of visual comfort and luminance level which reduced the need for the artificial light. However by modifying the ceiling geometry the louvers shading system increased the luminance level in the deep space and reduce the luminance level in front of the window through all the year time which helps to reduce large amount of lighting electric energy consumption and avoid the heat produced by the artificial light component. The result also showed the relationship by the louvers width and lovers tilting with the daylighting performance. Two scaled physical room models were constructed with 8 meter width, 6 meter length and 3.25 meter height. Both models were equipped by the louvers shading system. One of the rooms was constructed with flat ceiling and the other one with a curved ceiling. The two models were constructed using 1.2 mm thick plywood. The walls and the ground were covered with sheets that had a reflectance value of 71% and 35% respectively. The ceilings were constructed using a material that had a reflectance value of 81%. The windows were facing the south orientation with 5 meters length and 1.4 meters height, 90 cm sill height and 88% glass transmittance value. The horizontal louvers were constructed from 1 mm aluminum sheets with 81% reflectance value as figure 2.10. The louvers were generally fixed along the windows height with 30 cm distance between each louver. Eight luminance sensors (four for each model) with direct connection to the computer to store and analyze data were used to measure the interior luminance condition. Furthermore the models were tested under an artificial lighting in the laboratory in order to explore the model performance. But the real test was in Jordan under the real sky condition (clear sky condition) with daily measurements from 10am to 4pm during periods from March to October.

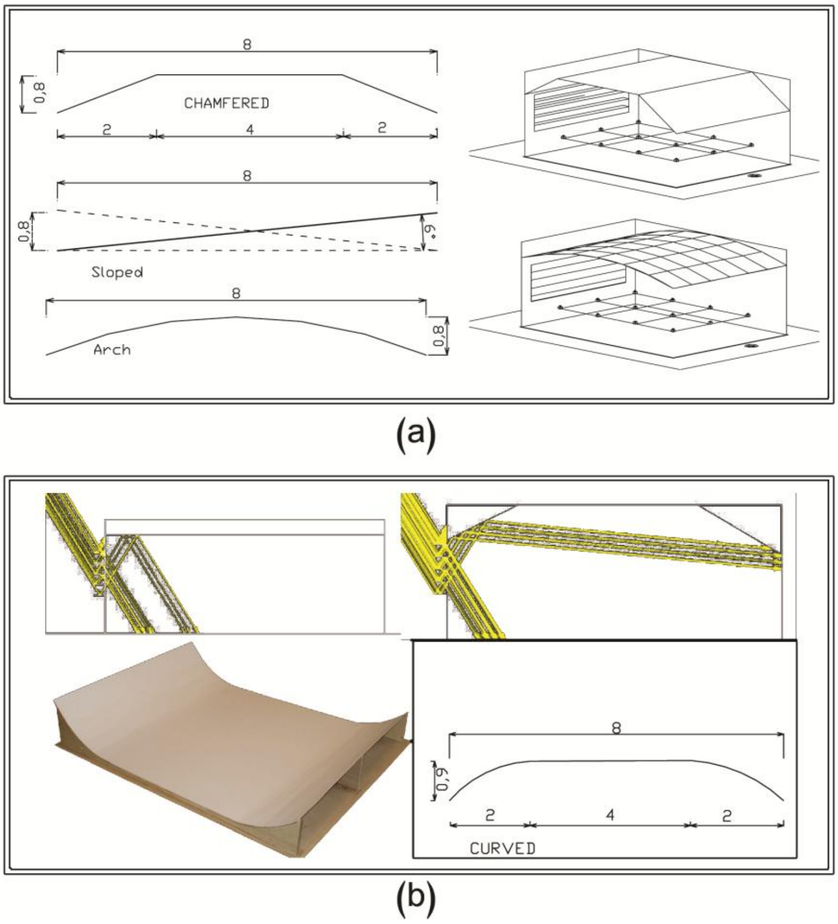



Fig.2.10. Ceiling geometry shape with louvers shading models, (a) Virtual model test, (b) physical model test. (Freewan et al, 2008).

Tzempelikos et al (2010) studied the interior thermal comfort in office buildings on a varying exterior climate conditions, glazing properties and shading devices. This study shows that the buildings envelop with high performance facade glazing and shading materials can enhance the indoor comfort conditions. In addition to this the shading manage strategy had important role in this terms.

Aghemo et al (2006) explored the optimum solution of using the shading devices in order to improve the indoor and outdoor environmental quality and at the same time to take the maximum benefit from the daylight in order to reduce the total energy consumption of the building by minimizing the use of the artificial light. However, the evaluation and the comparison between different internal and external shading systems were used on the building façade of simple high-school classrooms in all daylight time as figure 2.11. This simulation was done by testing a scaled model of the building under an artificial sun and artificial sky, which would allow the artificial sun light to get inside and outside the model in order to find the optimum design solution. The result of this research, using some shading devices like the internal and the external light shelves in certain configuration can produce a high illuminance and contribute to increase the daylight penetration into the deep plan which can help reduce the artificial light electricity consumption for the whole building and at the same time helps avoid the causes of visual discomfort like glare effect.

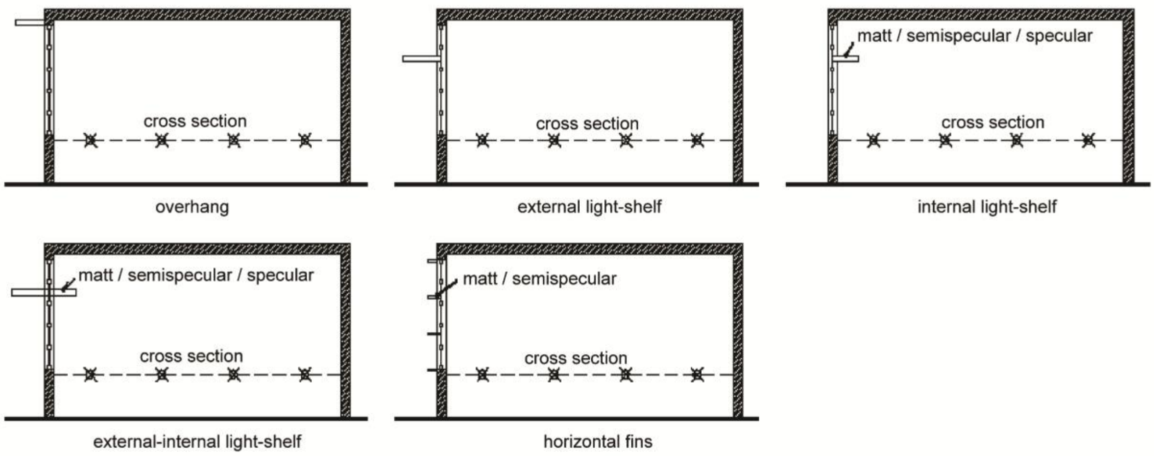



Fig.2.11. Different shading system applications were tested by Aghemo et al (2006).

Ho et al (2008) studied the effect of the sun-shading design in subtropical regions (Taiwan). This investigation studied the feasibility of fixing a shading device (four different shading devices with different luminance properties) in the classroom windows in order to provide the sufficient amount of luminance from the natural sun daylight or at least to minimize the use of the artificial light inside of the classroom. As a result, the artificial light power cost will be reduced which can help save the total energy consumption from the lighting power cost. Moreover, the total power of cooling loads could be reduced as a result of reducing the heat produced from the artificial light. An experimental measurement method was used by installing a number of photometer measurements in the classroom and the classroom was exposed to a natural daylight from one side only (southeastern). The investigation aimed at testing the different shading devices which were fixed in the southeastern façade windows as illustrated in figure 2.12.

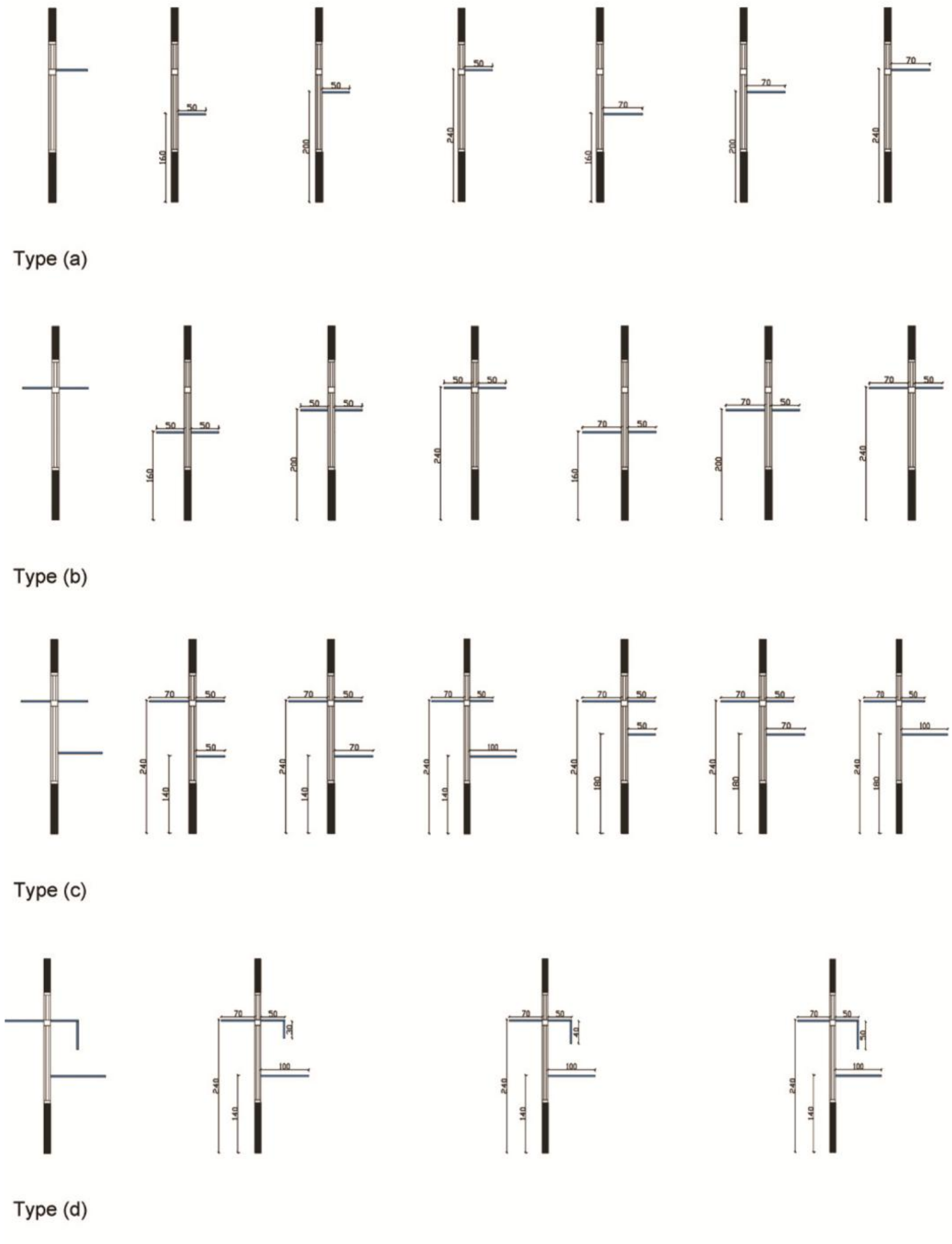



Fig.2.12. Different Sun-shading designs were tested: (a) single shading, (b) twin shading, (c) double-layered shading, and (d) double-layered shading with single vertical element. (Ho et al, 2008).

The illuminance condition was measured at the tabletop level which is 72cm high using a nine channel photometers with an accuracy of 2%.

The photometers were arranged in a rectangular array (15x9) with 9 columns and 15 rows with 80cm distance between each row and column. Finally the calculation process took around 15 min to record several measurements to ensure the reliability of the results. The study resulted that (the classroom lit from one side only by natural light) showed that it is possible to enhance the luminance condition by the natural light with 70% energy saving from the total lighting energy consumptions. This would occur by fixing a double layered sun shading with a single vertical element with a height of 240 cm, a width of 40 cm and a vertical element length of 40 cm in the windows.

Meng and Zhang (2006) were investigated the effect of the roof shading devices as shown in figure 2.13 in hot climate region to reduce the building temperature through the effect of the dark shadow which reduces the energy consumption as a consequence. Different varying factors were considered in the tested analysis like the current sky condition, sun position, calculation point, location and size of shading device. All the measurements were taken on the 21$^{st}$ of every month in order to evaluate the whole year shading effect. Some constant factors were also considered like the shading structure shape and distance between two shading blinds and so on. The visual shade (VS) calculation computer software was used to calculate the direct solar radiation transmittance in order to evaluate the shading effect. Finally, the field temperature measurements for shaded and unshaded areas were used in test. This study illustrates the relationship between the architecture and the climate. However in winter about 80% of the solar radiation can reach the building roof surface which is good to reduce the cold temperature but in contrast, in summer about 85% of the direct solar radiations were shaded by the roof shading device to enhance the indoor and the outdoor thermal comfort which help to saving large amount of energy consumption.

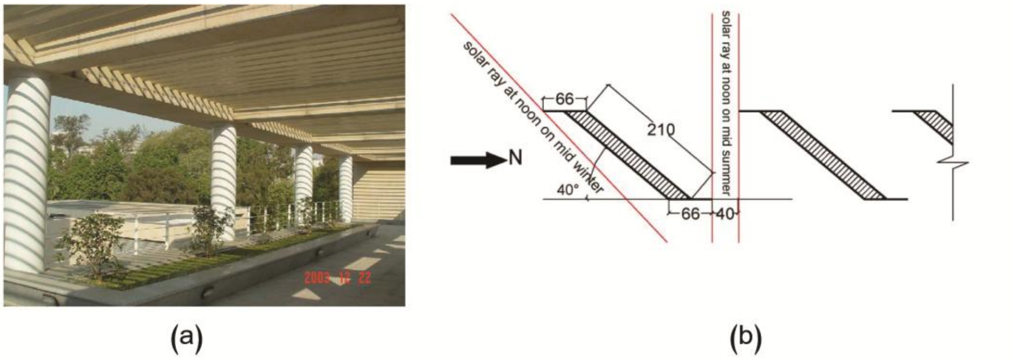



Fig.2.13. Rooftop shading application, (a) existing photo, (b) dimensions of roof shading device. (Meng and Zhang, 2006).

Moeseke et al (2005) investigated the impact of management strategies for external mobile shading and natural cooling ventilation systems in order to find the optimum solution to save building energy. The authors focused in this study to find methodology of the management strategies for external mobile shading. An office room with a total area of 19 square meters. The external walls had 40% glass; the glass thermal conductivity was 2.95 W/m K and a shading solar factor of 0.77, while the thermal conductivity for the window frame was 6.49 W/m K with a glass ratio of 0.3. Two sets of shading simulations were used in this study. In the first set the shading device was an exterior screen with two positions: closed (glass fully shaded) or opened (glass fully exposed) with a glass solar coefficient of 0.11 in both cases. In the second set the shading device proposed the overhangs shading system as can be seen in figure 2.14. The room thermal mass and temperature were also considered, a supposed internal gain of 35 W/m, two people (70 W for each), computer equipments (100 W), printers (14 W), internal lighting gain of (10 W/m2) and a 0.7 simulation factor was applied to all internal gains. Finally, the time of the simulations was from 8am to 6pm during all week days. The aim of these simulations was to investigate the efficient shading control that would reduce summer heat gain to enhance the interior temperature, and at the same time maximize the outer visual views without glare effect in order to have a comfortable working area and save the maximum energy. From the study result it can be noted that control modes for the shading devices can reduce the negative effect of the solar radiation especially in summer. The use of both shading systems (exterior blinds and overhangs) with the optimum management could be more effective if the year time (summer or winter) was considered before installing a shading device system.

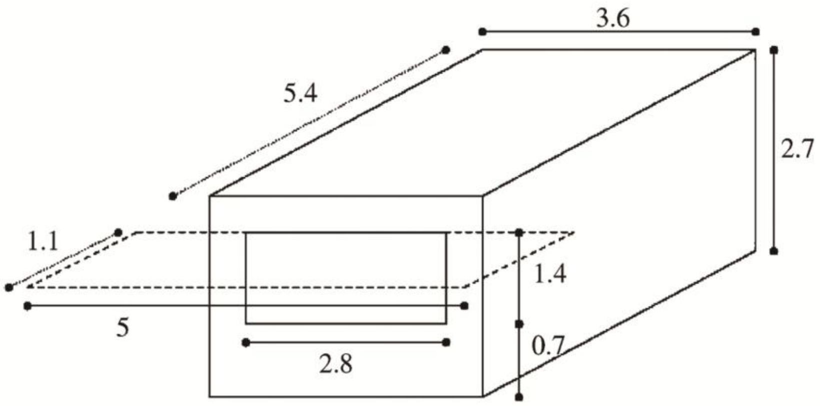



Fig.2.14. Model geometry and dimensions. (Moeseke et al, 2005).

Chen et al (2005) investigated the shading device performance that increased the preserved heat effect in a passive solar house in China during winter by installing a shading device in an air gap within a trombe wall to reduce the heat loss at night as been shown in figure 2.15. This would happen by opening the shading device at day time to allow the black massive wall to absorb the solar heat and closing it at night time to minimize the heat loss from the wall. two existing rooms were used in this study. One was used as a reference room and the other was used as a test room. The two rooms were divided with a 100mm thick Styrofoam panel, which made the volume of each room 3.9m (long) X 3.9m (width) X 2.7m (height). South facing concrete walls was constructed behind the double glazing windows to create the air gap. Light color shading devices were installed in the air gap to avoid overheat in summer and enhance the thermal performance in winter. Four rectangular vents were located in each of the massive walls; two at the top and two at the bottom. An external black wall with 300mm thick cinder and 100mm thick Styrofoam panels was constructed. A ceiling was made from 80mm thick concrete and 100mm thick Styrofoam panels. The measurements' recordings carried out from Feb 12-16 2004. In this investigation the main parameters measured were exterior and interior surface temperature of the massive wall, outer and inner temperature of the glazing, air temperature in the gap, outdoor temperature and solar radiation. Data were received every 10 min and then sent to the main computer so that they could be stored and analyzed as data-logger. Climate data like: wind speed, wind direction, relative humidity and temperature were considered and collected every 10 min. Hourly solar radiation accumulative value was measured by a computer software. Finally, all of this data were analyzed through computer mathematical operation according to the weather. Hence this study investigates the thermal performance of a trombe wall provided with a shading device placed inside an air gap during the night time. In General the results showed that the use of a shading device in the air gap in the trombe walls enhanced the thermal performance of the massive wall. Using a shading device can reduce the heat loss during the night time in winter with the optimum shading control from 20%-40% which enhances the indoor thermal performance.

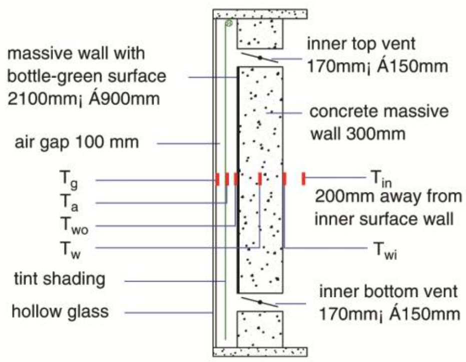



Fig.2.15. Schematic diagram of the structure and locations shading device of the Trombe wall. (Chen et al, 2005).

All of these studies and more reflect the range of importance and the efficiency of this façade technology in the modern building. In a country like the United Arab Emirates the needs of such sustainable innovative solutions to save the energy consumption and reduce the $CO_2$ emission become as a main demand by the time, this is because of the limited renewable source in this area, however the short virtual life of the classic source of energy the fossil fuels and the negative environmental impact of burning this energy.

## 2.3. Aims and objectives of this research:

The main aim of this thesis is to investigate the effectiveness of louvers solar shading devices for office buildings in UAE climate and to propose shading design guidelines and recommendations to improve the energy performance. Offices building facade with external louvers shading system and some natural daylight strategy integrated with light dimmable system present significant opportunities of saving energy and provide a comfortable working environment. The main aims and objectives of this study are:

1. Analysis of the office building energy saving in different proposed strategies and demand control potential by using a simplified model that considers the orientation, weather condition, the interior component, the louvers properties, the natural lighting performance, the HVAC demand and the electric performance.

2. Investigate the different of energy performance in office buildings façade with the base case scenario and shading installation scenario.

3. Investigate the optimum louvers shading design in terms of energy saving in this area:

- The optimum performance for the louvers ratio between louvers width and lovers spacing.
- The efficiency of using semitransparent materials in louvers plat.
- The effect of the louvers color material properties in energy performance.
- The optimum positions and configuration of the louvers shading system.
- The energy performances of using different louvers slate tilt angles.

4. Investigate the effect of the louvers properties in energy performance during the different four seasons.

5. Investigate the external louvers energy saving performance for the South, East and West scenario.

Moreover the study aim to identify the office buildings efficiency to enhance the building façade in order to save energy and to validate the best methodology in order to test the feasibility to implement the optimum design strategy in this term.

# Chapter 3: Methodology.

## 3.1. Selection and justification of the method chosen:

Many research methodologies were used to test the performance of the shading device. Each of these methods has negative and positive features. In the past the researchers relayed on manual tools with mathematical calculations to assess the shading performance. But nowadays modern research methods has been applied with different technologies and with a high accurate results such as the laboratory scaled model simulation, filed experimental measurement, computer simulation method and the computer mathematical calculations method. In order to select the suitable research method for this study brief outline for the advantages and disadvantages for each methodology will be explored:

### 3.1.1. Laboratory scaled model simulations:

Laboratory simulation is one of the widely used methods for shading testing. The small light wavelength made the behavior of light inside model at certain scale noticeably different to its behavior in the real space. Scaled model is give clear idea for researcher about what is happening in the design. This is very important to insure researcher's satisfaction about design outcome. Testing under artificial sky dome has very major advantage over real sky for ability to control sky conditions. The artificial sky can model different conditions by adjustable laminar around the domes frame in any location at any time during the year. Figure 3.1 shows artificial sky dome with scaled model used to test the shading device performance. Aghemo et al (2007) used the laboratory simulation as a research method to investigate and analyze the effect of daylight on a building by testing different shading systems. This simulation had been done by testing a scaled model of the building under an artificial sun and artificial sky, which would allow the artificial sun light to get inside and outside the model in order to find the optimum design solution. This method allowed the researcher to analyze and investigate in a three dimensional model with the same natural conditions and material properties. Also, the simulation of the scaled model under the artificial sun and sky gave the opportunity for the real materials to be used and allowed having the real environmental conditions. However, there were some problems with this method, especially with the physical model and the materials cost. There are different types of artificial sky that can be used in this method, with different properties for each one such as the mirror sky, dome sky and the spot light sky or the scanning sky simulators. In this research they used the scanning sky simulator which gave more flexibility to the study. As been noted by  Aghemo et al, (2007) there is some disadvantage points in this method related to the cost of the artificial sky, the physical model cost with the materials, the time need to model detailed complex buildings and the obstacle of scaling some innovative materials.

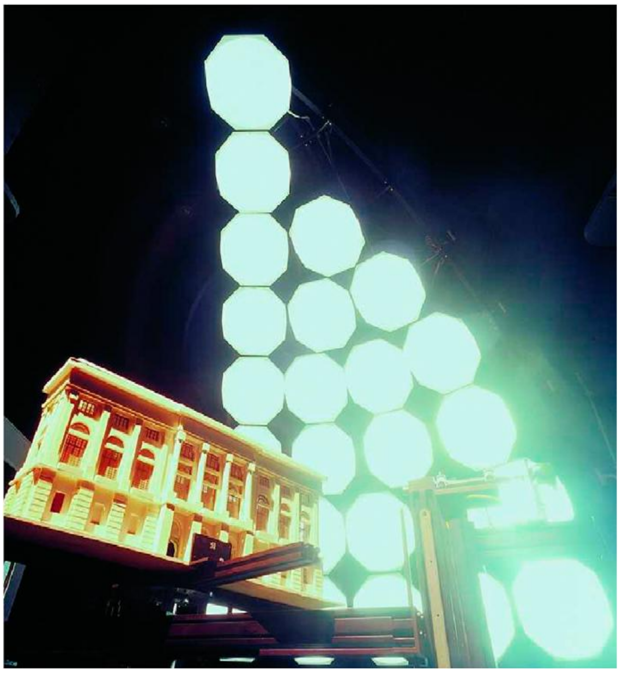


Figure 3.1. Artificial sky dome with scaled model used to test the shading device performance. (Aghemo et al, 2007).

Freewan et al (2008) used the laboratory experimental study on a physical model for testing due of the accurate results. The researchers used two different research methodologies in order to compare them and reduce errors to achieve the reliable results. The researcher used the laboratory simulation with a physical scaled model and the computer simulation with a virtual one. The objective of the physical experimental study is to provide data of the material and the real sky condition properties for the computer study to assess the ceiling geometry with the louver performance. Another objective of the physical experiment was to verify and validate the computer simulation.

### 3.1.2. Field experimental measurement:

The field measurement investigation aim to collect data of shading effect from the experimental site or the selected built area, shading performance through use the effect of shading device on sun solar radiation. But also there are some shortages with this method as the following, the availability of some technologies equipment, the measurement time (taking a yearly measurement sometime), the difficulty to use this method in some experimental area and the highly cost of measurement equipment. Ho et al (2008) used two different methodologies in order to compare between them (the computer simulation and experimental measurement) and validate the simulation methods. The experimental measurement method was used by installing a number of photometers measurements in the classroom as been illustrated in figure 3.2.

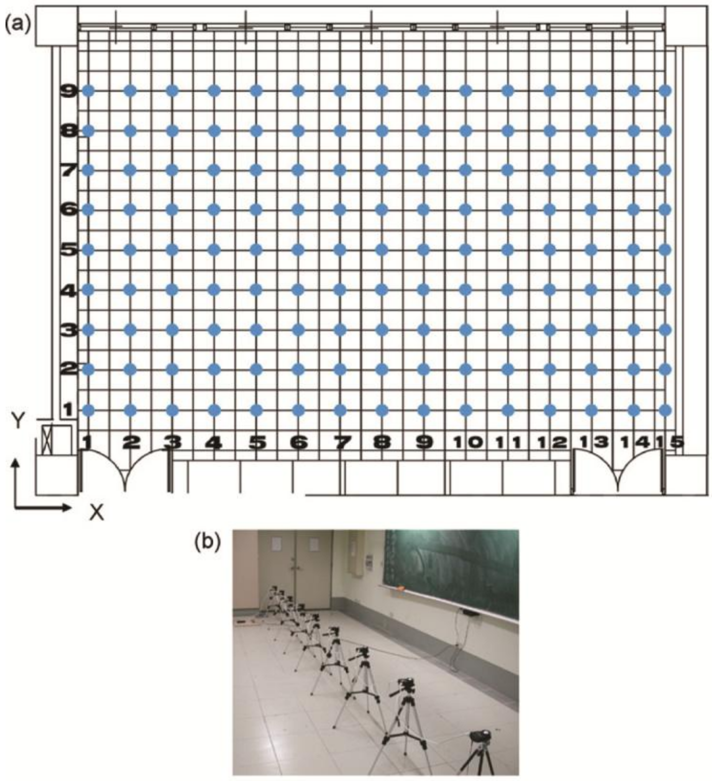



Figure 3.2. (a) Illumination measurement positions in model classroom. (b) Photograph
Showing single row of multi-channel photometers meters in one row of Measurement array. (Ho et al, 2008)

Sutter et al (2006) used the experimental field measurement study as a research method. He selected eight individual offices in one building, all of them with the same orientation, facing South East façade. The offices equipped with manually remote controlled black blinds because the black color offers a wider range of transmittance than lighter colors. In these offices the workers were two men and six women and 70% of the work was in front of the computer. The measurements were taken every 15 min during the work time within a period of 30 weeks. The measurements were collected for the following data:

- The vertical global outside illuminance (measured from the window surface).

- Measured the illuminance on the top of the computer screen (by measurement sensor).
- The accurate position of the blinds (the angle of the slats and height above sill).
- The state of the artificial lighting (on/off).
- The indoor temperature.

The blinds were fitted with the encoding motors with direct connection to the central computer to analyze the data of the blinds position. Illuminances were measured by different measurement sensors and other sensors placed in the ceiling to record the artificial light state and the environment temperature. Finally in this experiment they used a digital camera with calibrated illuminance.

### 3.1.3. Computer simulation:

Computer simulations give very wide options for changing parameters and study shading effect and daylight in different locations. Simulations calculate quantity values like illuminance and thermal heat gains. Results can be presented by different outputs as real image, false color mapping or presenting values in numeric numbers. From the different articles analysis the researchers were used different software programs to simulate the shading effect like: TRNSYS, REDIANCE, and LIGHTSCAP moreover there are new software has been used with strong recommended and validity from several researchers like: IES-VE, ECOTECT 2010 and 3D MAX DESIGN. The computer simulation allow the researcher to investigate the lighting factors, shading factors, thermal factors and any environmental factors in any latitude, under any condition and at any years periods. Moreover the simulation time is shorter than any different methods. From all above the advantage of using the computer simulations has been illustrated in these points: Saving time, saving money, possibility of simulating in any latitude, possibility of simulate in any sky conditions, providing all the climate data with any periods, possibility of using any materials properties, validity, widely options for changing parameters, Possibility to simulate the large scale model like (urban scale) and availability.

Hammad and Abu-Hijleh (2010) used the computer simulation as a research method in order to explore the influence of the external dynamic louvers shading system on the energy consumption for office building. The researchers were investigated the energy saving effect of using the dynamic louvers by using the integrated environmental solutions-virtual environment (IES-VE) software simulation due the wildly advantages of this method like the availability, the development of robust advanced, the flexibility of environmental control and the time saving. But on the other hand the computer simulation needs high validated software and a proficiency of the user of this software.

Ho et al, (2008) used computer simulation methodology by used LIGHTSCAP illuminance simulation software. But there are two different luminance estimating techniques which are usually used in the software simulation, the (radiosity) technique and the (ray-tracing) technique. In the radiosity technique the interior area is divided in to a mish with certain number of ordinate, each ordinate is considered to be a lamb reflector with constant luminance and each ordinate receives and reflects light in the space. The whole process kept continuing until all of the reflected flux was absorbed. This technique could model uniform standard overcast sky, clear sky or without sun condition. Finally, it should be noted that radiosity algorithms cannot have an accurate simulation for the reflective surfaces. In contrast, the ray-tracing technique gives a simple estimating luminance condition in the space. In the ray-tracing technique the ray emitted from the light source is traced from the surrounding surfaces. This way excels in the rendition of light source point, reflection and refraction effect. But in this technique the calculations are dependent only on the geometry of the environment. The LIGHTSCAP software uses both estimating techniques that are used to estimate luminance condition in this research. However, this software allows the researcher to estimate the effect of the natural daylight and the artificial light by applying these light factors to a virtual scaled model of the building with certain properties for all objects. The calculations in this software assume a virtual environment condition under a virtual modeled dome sky with the same real condition properties.

Freewan et al, (2008) used the REDIANCE computer software as a computer simulation methodology, this software used both calculation techniques (radiosity and ray tracing) REDIANCE is an artificial light and daylight calculation, visualization and analysis program, and it can easily deal with the complex building form under the clear sky or the overcast sky conditions. First, the virtual models of the two rooms were created using AutoCAD software with adding all the materials. The computer simulation was carried out through the same time. Finally the output results of the computer simulation were similar to the experimental results; therefore the REDIANCE software can be used in any light simulation with high validity and accuracy.

Palmero-Marrero and Oliveira (2009) used the computer simulation only as a research method. The main goal of this research is to test the effect of louvers shading system performance on the building by estimating the building energy consumption for the same building geometry under various climate conditions. Initially the simulation used one building form. The (TRNSYS 16) simulation programs were used to create the building model and the final simulations. The climate data were obtained through METEONORM program, which was provided by TRNSYS. TRNSYS type 65 was used to define the geometry and material properties.

James and Bahaj, (2004) used the computer simulation method to study the smart glazing solutions to glare and heat gain, this study used the TRNSYS software programs in order test the efficiency of different façade solutions (mechanical, glazing solution or shading solution) in terms of avoid glare and reduce heat gain.

Moeseke et al (2005) used the computer simulation to analyze the shading effect in this article. The numerical dynamic simulations then used the TRNSYS 16 computer software to test the external blinds and overhangs shading performance. The impact of the shading devices management was examined in the TRNSYS 16 with long term weather data.

Al-Sallal (2006) tested the glare effect in universal space design studios in Al-Ain UAE. The researcher used the experimental methodology with the computer simulations method in order to test the glare effect by used the ECOTECT software programs with RADIANCE software program. The study aim to investigate the optimum position of shading reflector to avoid glare and enhance the interior space.

### 3.1.4. Computer mathematical calculations:

These methods were using the computers mathematical formulas to test shading in the space. Usually the researchers were used this way instead of the manual calculations. Meng and Zhang (2006) used the visual shade (VS) computer software in order to calculate the direct solar radiation transmittance in order to evaluate the shading effect. The importance point of this method is the researchers always need some measurements parameter from the experimental site to complete the formulas data.

Collins et al (2007) studied the effect of heat transfer for fenestration with between the glass louvered shading by used the numerical mathematical calculation method.

## 3.2. Conclusion:

In summary, methods of testing shading effect varied from the past integrate many types of classical mathematic, model types and simulation software. All the new technologies has been considered an important tools with high accurate results, moreover the different methodologies supports each other's by comparing the final output for each of this methods. From all this data it can be said that the best investigation research methods nowadays is the computer simulation method. Because of the wildly use of this methods from most of the researcher, the advantages of usability and the software update which enhance the simulation process. Some researchers used two or three methods in one investigation in order to validate the output results, which is very important in some area studies. The advantages and disadvantages for any methods are depending on different characters for the analysis process like: The accuracy of the output data, the total cost of this process, the remaining process time, tools availability, options and validity.

## 3.3. Selected methodology:

Based on the above comparisons, the computer simulation method will be used to test the optimum external louvers shading design in terms of energy saving and the glare effect. This method chosen due a number of the advantages of the computer simulation method as the following:

- Saving time.
- Saving money.
- Possibility of simulating in any latitude.

- Possibility of simulating in any sky conditions.
- Providing all the climate data with any periods.
- Possibility of using any materials properties.
- Validity.
- Widely options for changing parameters.
- Possibility to simulate the large scale model like (urban scale).
- Availability

In addition, the wildly recommended from the researcher of using the computer simulation in all the similar topics and the accurate result of this method, but with the consideration of selecting the best software program and the proficiently of the user.

## 3.4. Selected computer software (IES-VE):

Crawley et al, (2008) conducted a comparison of the features and capability of twenty major building energy simulation programs. Table 3.1 illustrates an overview of tool support for solving the thermo and physical of zones for different twenty simulation programs.

Table 3.1. Overview of tool support for solving the thermo and physical of zones for different twenty simulation programs. (Crawley et al, 2008)

| | BLAST | BSim | DeST | DOE-2.1E | ECOTECT | Ener-Win | Energy Express | Energy-10 | EnergyPlus | eQUEST | ESP-r | IDA ICE | IES 〈VE〉 | HAP | HEED | PowerDomus | SUNREL | Tas | TRACE | TRNSYS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Interior surface convection | | | | | | | | | | | | | | | | | | | | |
| • Dependent on temperature | X | X | | | | | P | | X | | X | X | X | | X | X | X | X | | X |
| • Dependent on air flow | X | | | | | | X | | P | | X | | X | | X | | | X | | E |
| • Dependent on surface heat coefficient from CFD | | | | | | | | | E | | E | | X | | | | | | | |
| • User-defined coefficients (constants, equations or correlations) | | X | X | X | X | | | | X | | E | R | X | | X | X | X | X | | X |
| Internal thermal mass | X | X | X | X | X | X | X | X | X | X | X | X | X | | X | X | X | X | X | X |
| Automatic design day calculations for sizing | | | | | | | | | | | | | | | | | | | | |
| • Dry bulb temperature | X | X | X | X | X | X | X | X | X | X | | X | X | X | X | P | | X | X | |
| • Dew point temperature or relative humidity | | | X | X | | X | X | | X | X | | X | X | X | | | | X | X | |
| • User-specified minimum and maximum | | | X | X | | X | X | | X | X | | X | X | X | X | | | X | X | |
| • User-specified steady-state, steady-periodic or fully dynamic design conditions | | | X | | | | | | | | | X | X | X | | | | X | X | X |

X feature or capability available and in common use; P feature or capability partially implemented; O optional feature or capability; R optional feature or capability for research use; E feature or capability requires domain expertise; I feature or capability with difficult to obtain input.

Refer to Table 3.1. The IES-VE software achieved a high score as comprehensive environmental simulation software.

The IES <VE> is an integrated suite of applications linked by the software interface and single integrated data model include (Crawley et al, 2008):

- Model IT- geometry creation and editing.
- Apache Calc- loads- analysis.
- Apache Sim- thermal.
- Macro flo- natural ventilations.
- Apache HVAC- component- based HVAC.
- Sun cast- Shading visualization and analysis.
- Micro flo- 3D computational fluid dynamics.
- Flucs pro/ radiance- lighting design.
- DEFT- model optimization.
- Life cycle- life- cycle energy and cost analysis.

• Simulex- building evacuation.

The program work with the building geometry as input and uses international data on climate conditions and the typical characteristics of different buildings components, zones and operational system in order to provide feedback on the building energy consumption and carbon dioxide emissions. IES released the VE-toolkits which intended specifically to be used by architect for early design decisions in order to asses the building energy performance. The <VE> toolkits include tools for analyzing building energy consumption, carbon emissions, LEED daylighting, Solar shading, and artificial lighting. However it integrated around a central 3D virtual model that can be connect directly with different common software like sketchup, Revit, and other 3D design tools via the *.gbxml format. See figure.3.3.

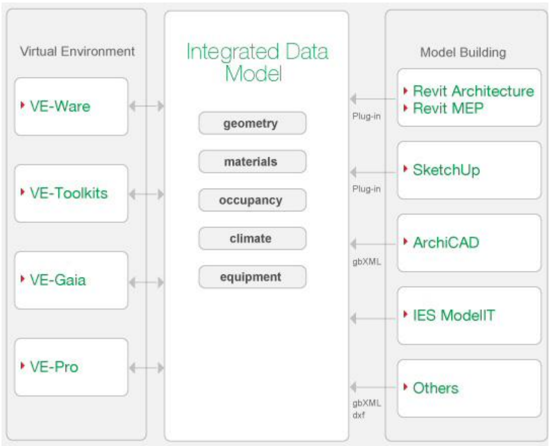


Figure.3.3. The IES product family, showing new and existing product and how they work with an integrated data model that be input directly from popular CAD and BIM application. (www.iesve.com).

Moreover the IES offers the same ease of use and quick feedback capabilities as the VE-Toolkits, but also provides users the ability to input exact building data and manipulate models. Smart navigation that includes analysis workflows for varied sustainable design tasks such as climate review, availability of natural resources, building metrics, materials use, water usage, energy/carbon, daylighting/solar, renewable/low carbon technologies, occupant comfort, passive design strategies, and others. (www.iesve.com).

## 3.5. (IES-VE) validation:

The validity of IES-VE software concerns the computer simulation to real results. This software has been validated and approved from different environmental authorities such as the American Institute of Architecture (AIA), Communities and Local Government (CLG) and Energy Balance Evaluation (EBE). For more information about this environmental software and its validity visit the IES-VE website www.iesve.com .

Moreover the model was reviewed by IES technical group and other professional software users during different sessions.

# Chapter 4: Simulation Model

## 4.1. Introduction:

High rise office buildings in Dubai gradually become a tendency for modern architecture and all of them are encouraged to be built with reinforced concrete as a building structure. Meanwhile, glass curtain walls also become one of the most popular façade construction materials in many high rise commercial buildings in order to have a modern, elegant and stylish building. In Dubai office Building scenario most of the buildings were built by using the modern construction materials which are commonly used in UAE. This simulation study will take one of the typical high rise office building in Dubai with the consideration of the existing building parameters and the current construction materials properties. The following part consist of a description of the chosen existing office building as well as the construction materials properties.

## 4.2. Building description:

Saba office tower is an ideal existing case study due the building parameters, building orientation, construction materials and building layout features. Main curtain glazed façades were constructed from the all building sides as described below in figure 4.1. The building contains 36 floors, located in the Jumairah Lake Towers (JLT) in Dubai. This building plot size is similar to the typical plot area, however most high rise buildings footprints in this area are approximately 35mX40m. The building plan contain a central core consist the stair cases, building services and elevators with diminution of 9mX11m as figure 4.2. The tower has a total structure height of 150m. The ground floor have a maximum of 4 office units per floor, floors 1 to 15 have a maximum of 6 office units per floor, floor 16 to 30 have a maximum of 4 units per floor, while floors 31 to 34 have a maximum of one office unit per floor. Thus Saba tower has over 33,445 square meter of office space in total.

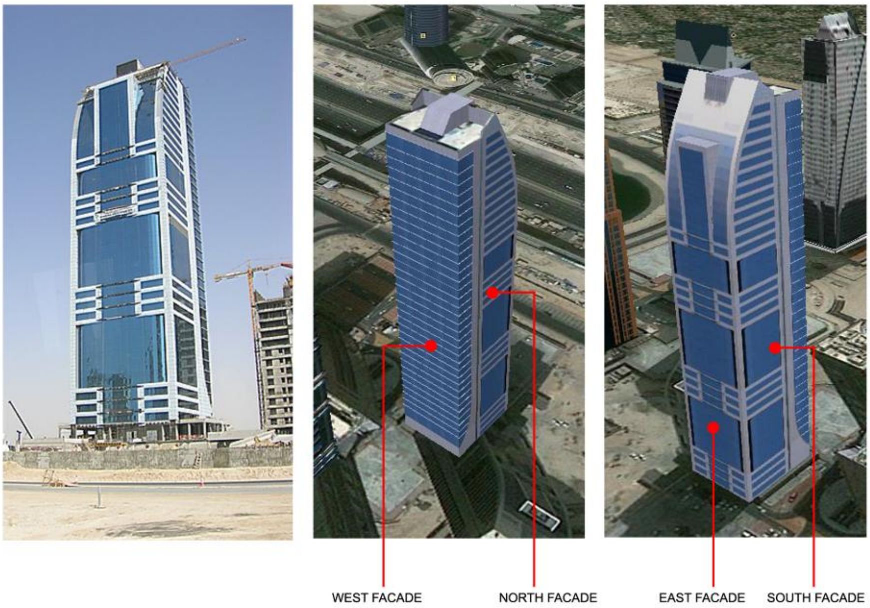



Figure.4.1 The Saba tower building façade. ([www.googleearth.com](http://www.googleearth.com)).

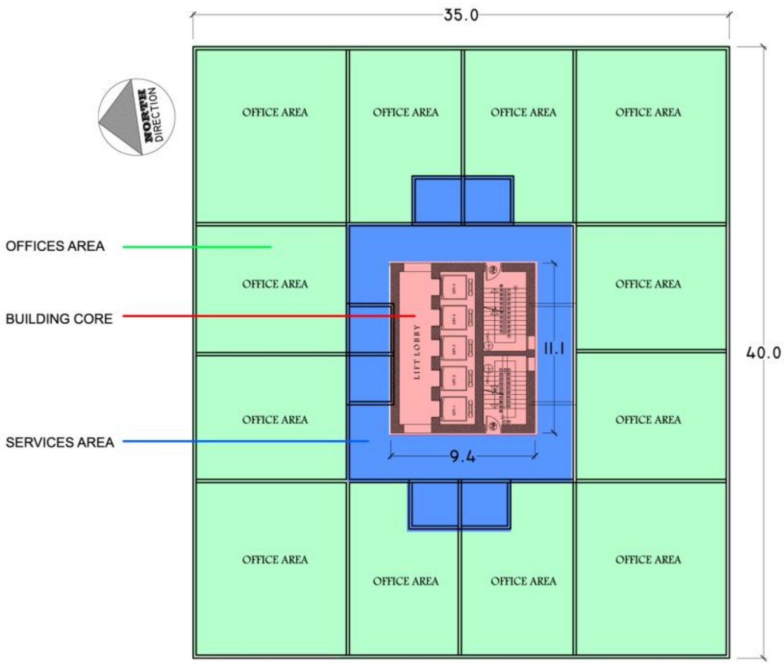



Figure.4.2 Saba tower building layout.

Minimum setbacks of 40metres from the neighboring towers as described below in figure 4.3.

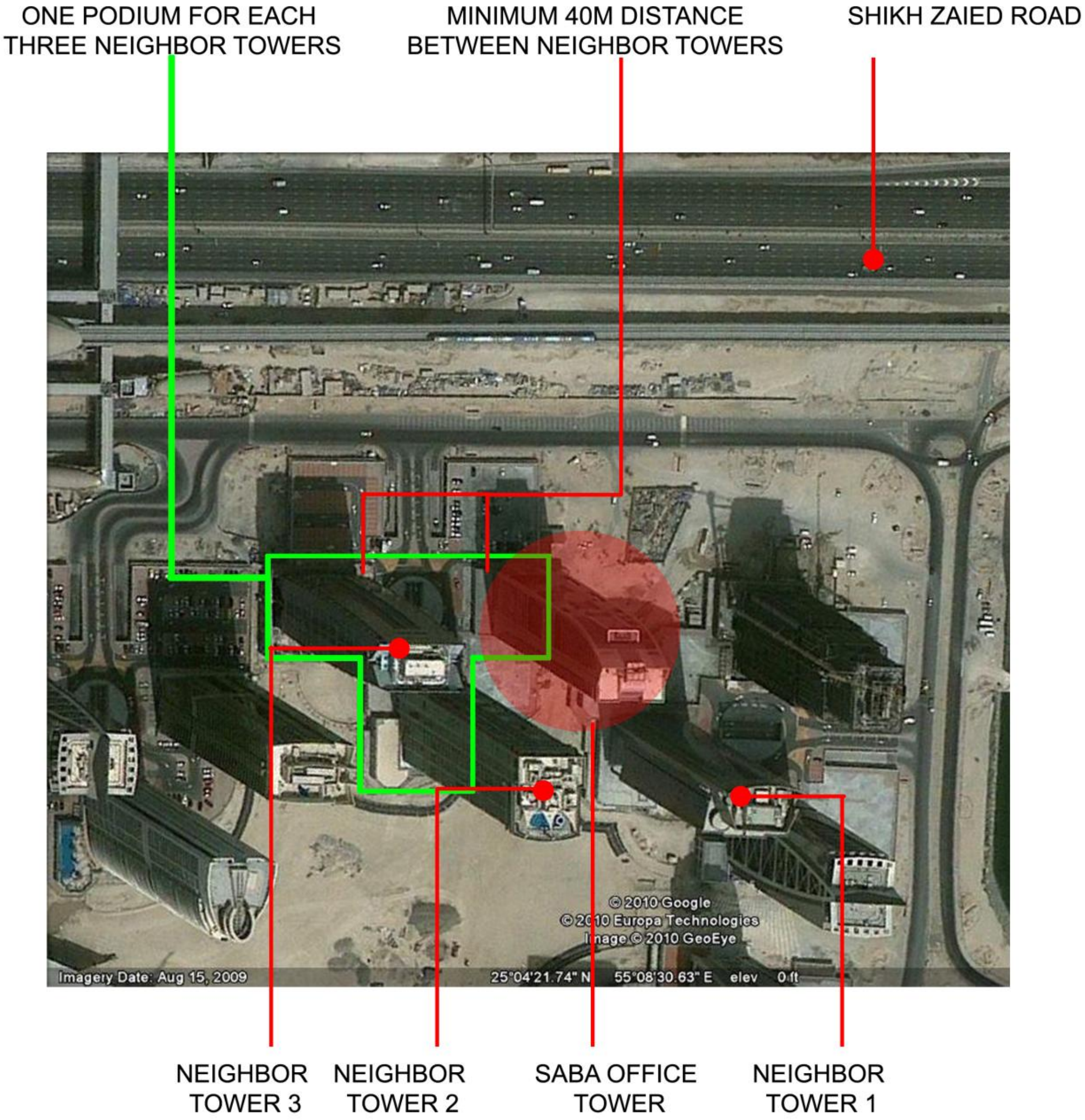



Figure.4.3 Saba tower site plan layout. (www.googleeart.com).

## 4.3. Building construction materials and finishes:

The following building materials data of Saba tower have been used in IES-VE construction materials database in order to simulate a typical single office unit for the South, East and West façade as been illustrated in figure 4.4.

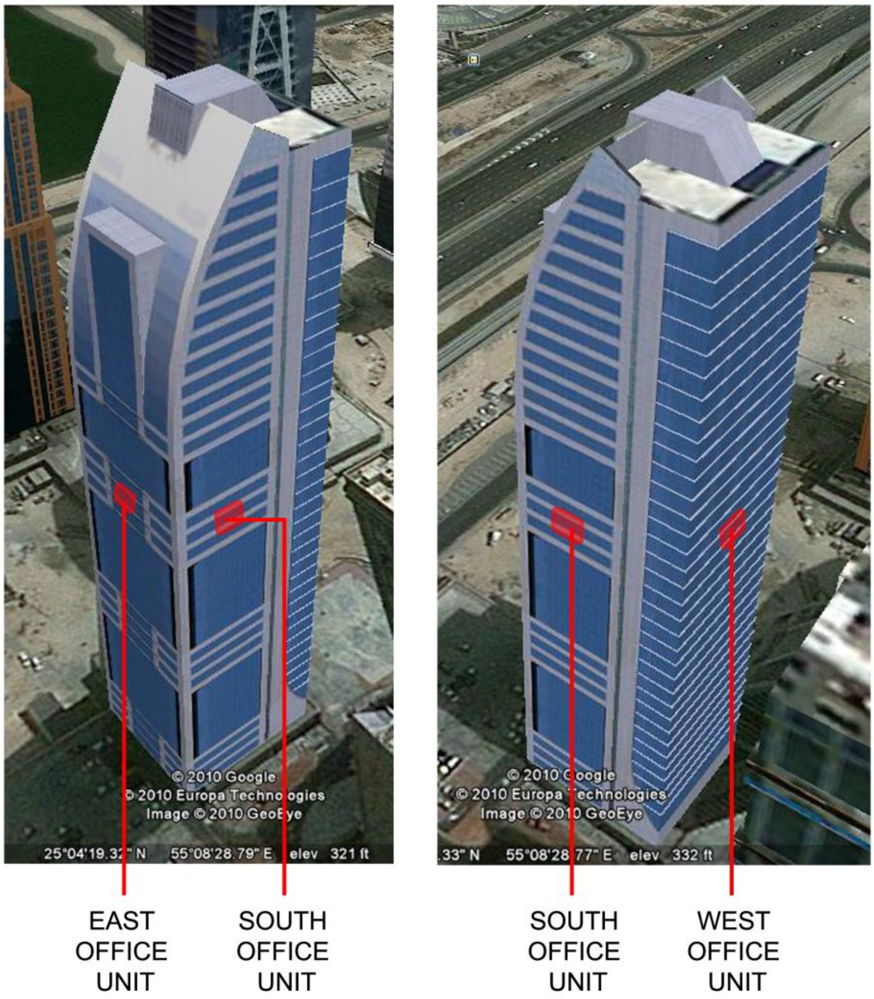



Figure.4.4. Four selected typical offices unit position from Saba tower on the south, east and west facade. (www.googleearth.com).

This construction materials layers define the thermal properties for building elements which has an important role in the building thermal performance. The construction materials have been used in IES-VE database for the following building elements as been mentioned in figure 4.5:

- External walls construction materials and finishes layers.
- Internal partition materials and finishes layers.
- Ceiling materials.
- Flooring construction materials and finishes layers.
- Doors properties.
- Glass or window properties.

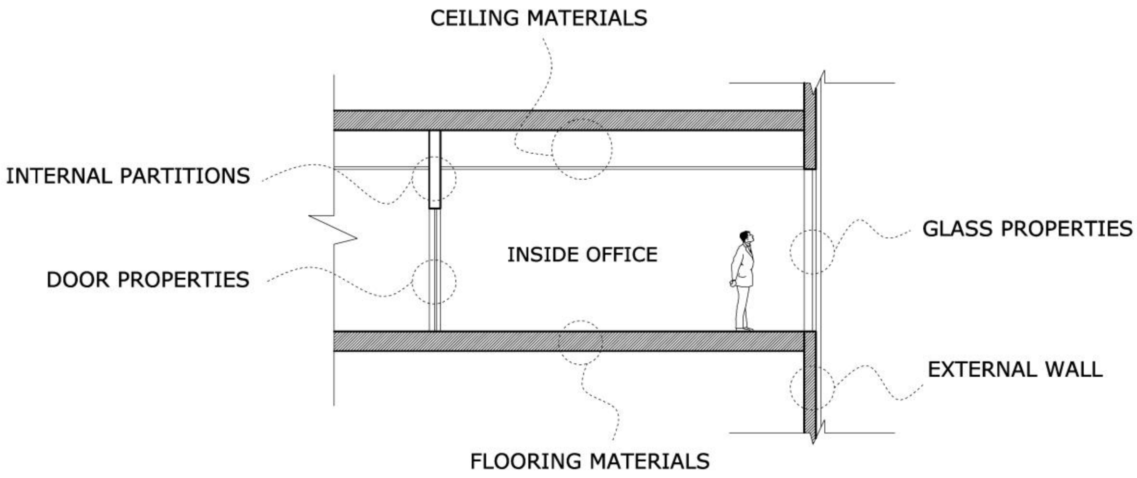



Figure.4.5 Six building elements considerate in order to simulate a single office unit.

These construction materials and finishes layers for all previous building elements of a single office unit in Saba tower have been illustrated in figures 4.6, 4.7 and 4.8.

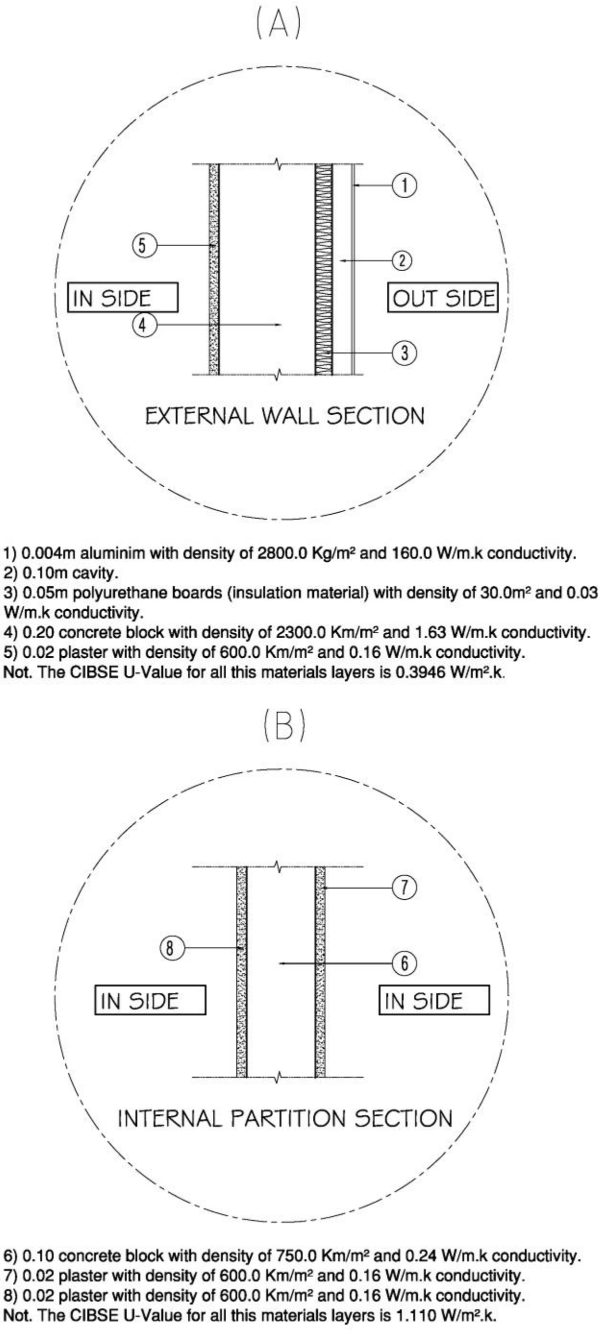
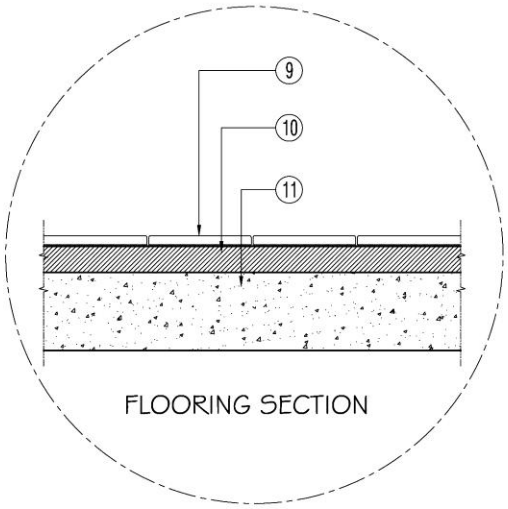


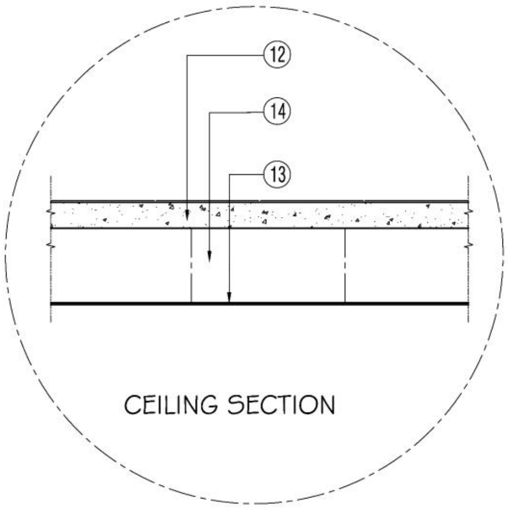

Figure.4.6 Sections show Saba tower construction materials and finishes properties, (a) external wall section, (b) internal partition section. (Saba Real Estate).

(A)




09) 0.04m granite with density of 2100.0 Kg/m² and 1.70 W/m.k conductivity.
10) 0.05m screed layer with density of 1200.0 Kg/m² and 0.41 W/m.k conductivity.
11) 0.20 heavy weight concrete with density of 2400.0 Km/m² and 1.43 W/m.k conductivity.
Not. The CIBSE U-Value for all this materials layers is 0.794 W/m².k.

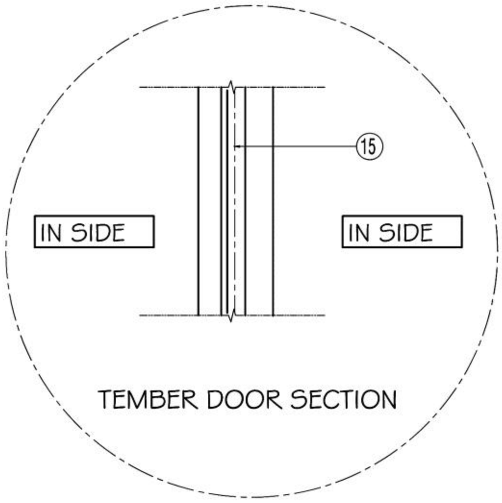
(B)




12) 0.25 heavy weight concrete with density of 2400.0 Km/m² and 1.43 W/m.k conductivity.
13) 0.004m aluminium ceiling with density of 2800.0 Kg/m² and 160.0 W/m.k conductivity.
14) 0.60 cavity.
Not. The CIBSE U-Value for all this materials layers is 0.1932 W/m².k.

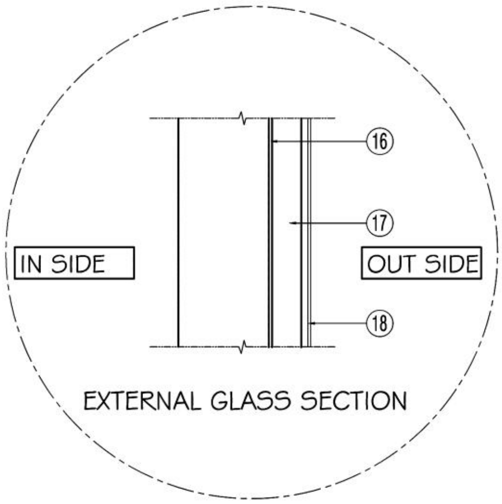
Figure.4.7 Sections show Saba tower construction materials and finishes properties, (a) flooring section, (b) ceiling section. (Saba Real Estate).

(A)




15) 0.040m tember door with density of 419.0 Kg/m² and 0.14 W/m.k conductivity.
Not. The CIBSE U-Value for all this materials layers is 2.1608 W/m².k.

(B)




16) 0.006m pilkington glass with transmittance valu of 0.44 and 0.33 and exterior reflictance and 0.15 inside reflectance.
17) 0.012m cavity.
18) 0.006m clear float glass with glass transmittance valu of 0.663 and 0.33 exterior reflectance and 0.27 interior reflectance.
Not. The CIBSE U-Value for all this materials layers is 1.95 W/m².k and the glass total shading cofficient is 0.41.

Figure.4.8 sections show Saba tower construction materials and finishes properties, (a) timber boor section, (b) external glass section. (Saba Real Estate).

Refer to figures 4.6, 4.7 and 4.8 some key parameters of construction materials properties have been used in the IES_VE construction database as been presented in figure 4.9. This construction data will affect the simulation results. Therefore the listed below and detailed explained of this key parameters as been mentioned in ASHRAE Fundamentals handbook, (2009) and (IES materials menu) in order to achieve accurate analyses simulations. The lists will include glass shading coefficient, U-value, thermal coefficient, transparency, conductivity and emissivity.

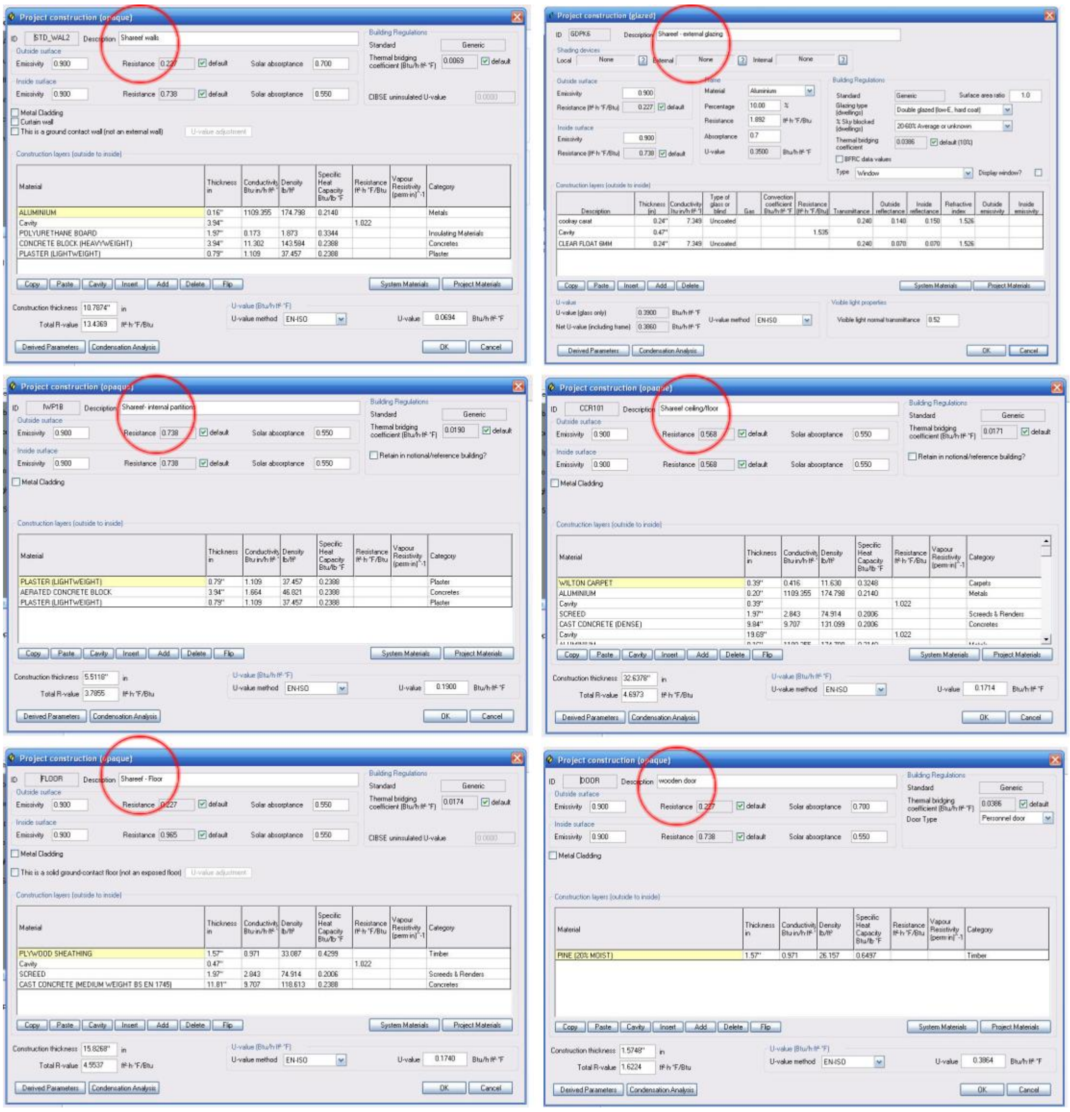


Figure.4.9. IES-VE construction materials database for the selected office. (IES building template manager database).

- The glass shading coefficient indicates the ability of glazing to block solar radiation. Low shading coefficient value means lower solar heat gain penetrated through the glass. Furthermore solar transmittance and reflectance value have a very important role in this term.

- The U-value is basically the air to air thermal transmittance of building materials due to the thermal conductance of its constituent material and the convective and radiation effects of its surface.

- Thermal coefficient in IES is expressed as a number between (0) to (1). However the high thermal coefficient value is preferred in solar heating application to capture maximum sun radiation.

- Transparency in IES shows the condition of being transparent.

- Conductivity in IES shows the transmission of heat across materials and the ability to transmit from higher to lower temperature.

- Emissivity in IES refers to the capability of this element to radiate long-wave radiation.

## 4.4. Office model:

As been mentioned before the simulation study will be for a typical single office unites in Saba office tower for the North, East, West and South façade as been illustrated in figure 4.10. A typical office room with rectangular shape of 4m (length) X 7m (width) X 3.6m (height) was constructed by using the modelIT tools on IES in order to test the effect of external louvers shading device on building energy performance, full glazed curtain wall façade from flooring to ceiling level with dimension of 2.7m (height) X 4m (length) as been illustrated in figure 4.10. External horizontal lovers with different diminutions properties were constructed for the south façade test, vertical louvers will be used for the east and west façade simulation test as been recommended in the daylight guidelines provided by Building Technology Department at the Lawrence Berkeley National Laboratory cited in Hammad and Abu-Hijleh (2010) as figure 4.11.

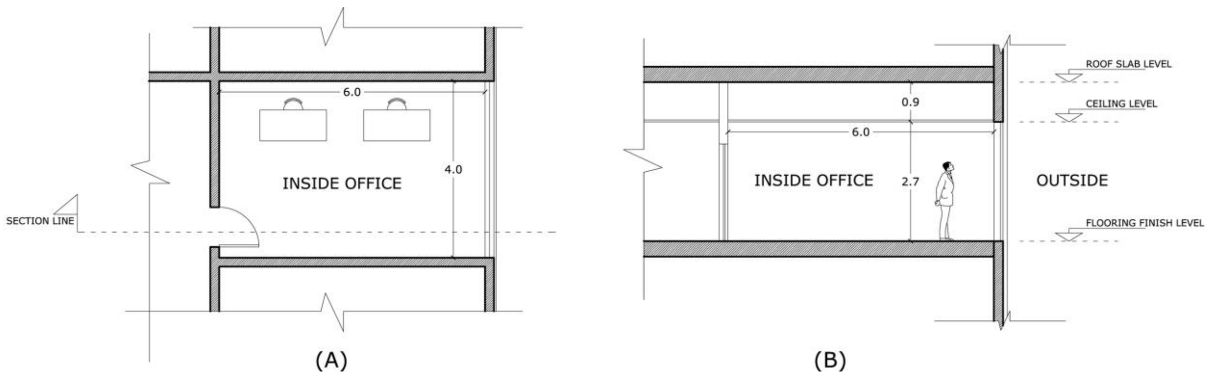
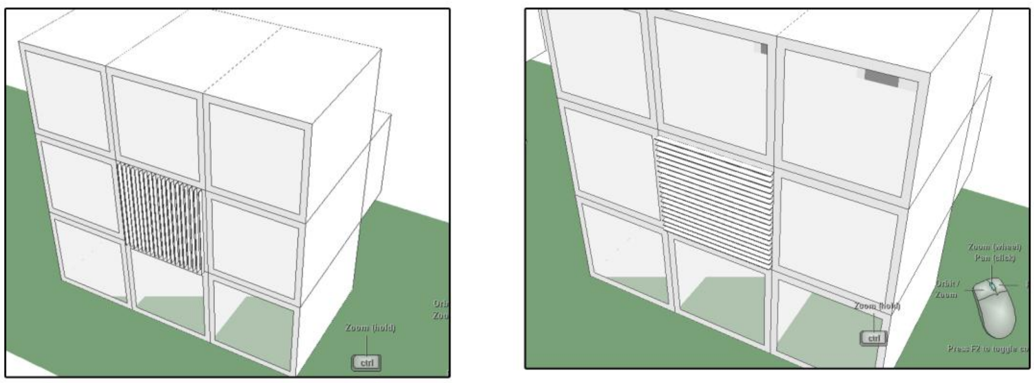



Figure.4.10. (a) typical office units plan, (b) typical office units section.



(a) (b)

Figure.4.11. Office unit, virtual model on IES. (a) Vertical external louvers installation for the East and West façade, (b) horizontal external louvers installation for the south façade.

The office was assumed to accommodate two work stations with two computer units with assumed power of 370W with two workers with maximum sensible gain 90.0 W/person and Internal lighting luminance of 500 Lux was fixed based on the Illuminating Engineering Society of North America (IESNA) standards (block, 2000) cited in Hammad and Abu-Hijleh (2010) as figure 4.12.

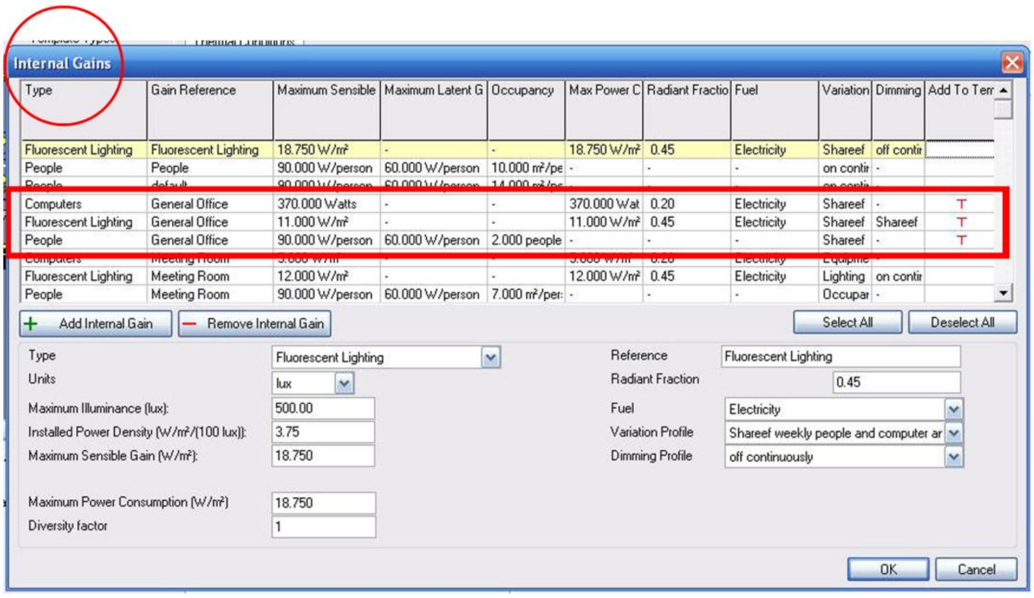



Figure.4.12. IES-VE internal gains menu were used in simulation. (IES building template manager database).

The cooling system was assumed to be on all the time with constant internal temperature set of 24° and 0.25 air changes/hour infiltration rates as shown in figure 4.13 and figure 4.14. Dimming lighting sensor was fixed on the ceiling level with 2m distance from the external window in order to maintain automatically the artificial lighting level during all the operation time to provide 500 Lux on the working disk level. Fluorescent luminaries lighting unit was fixed on ceiling level at 2.8m high with installed power density of 2.2W/m²/100lux. Figure 4.15.

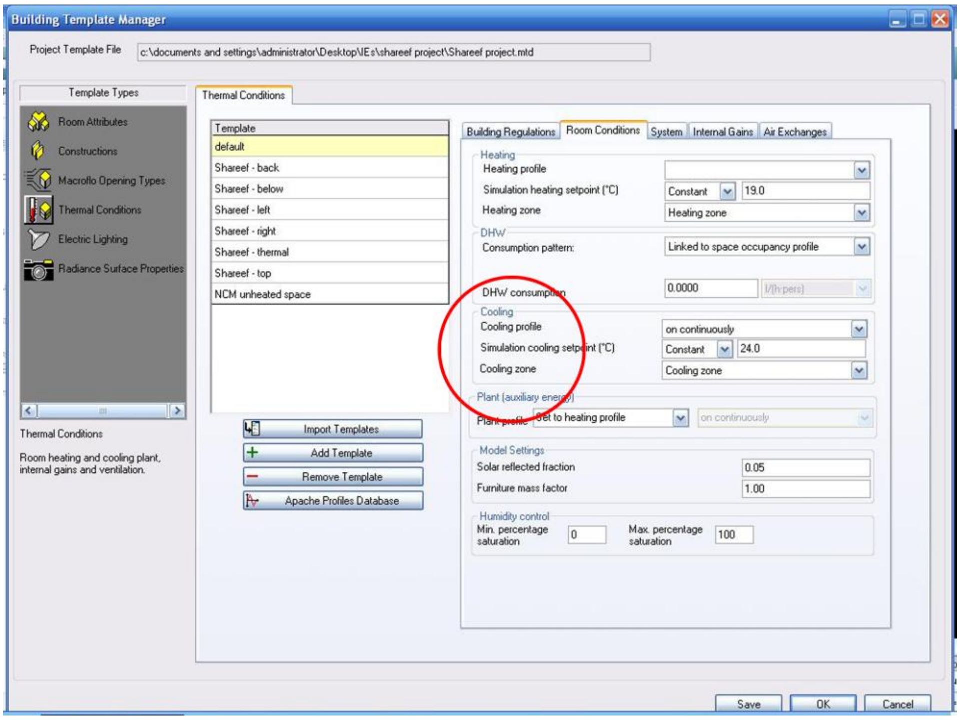



Figure.4.13. IES-VE cooling system menu for the single office simulation. (IES building template manager database).

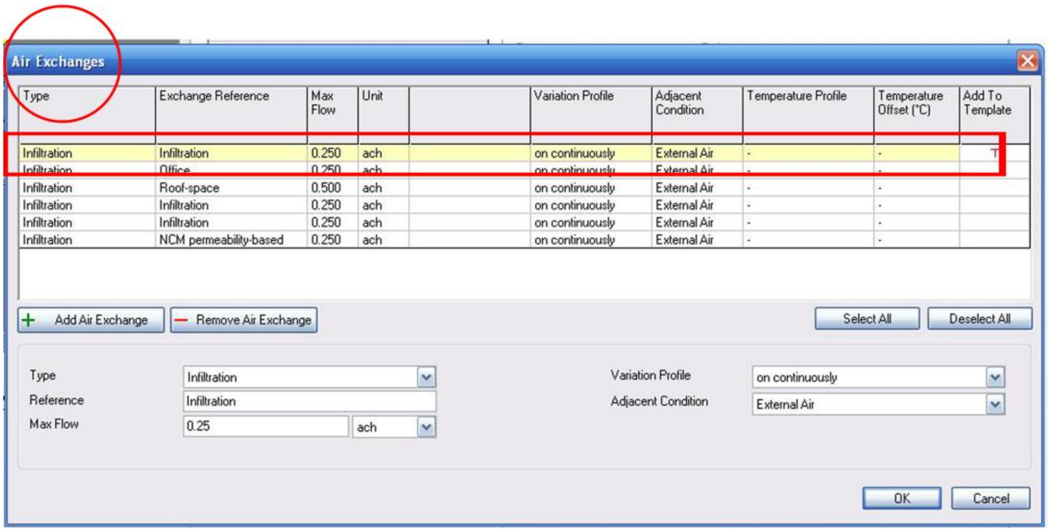



Figure.4.14. IES-VE air exchange menu. (IES building template manager database).

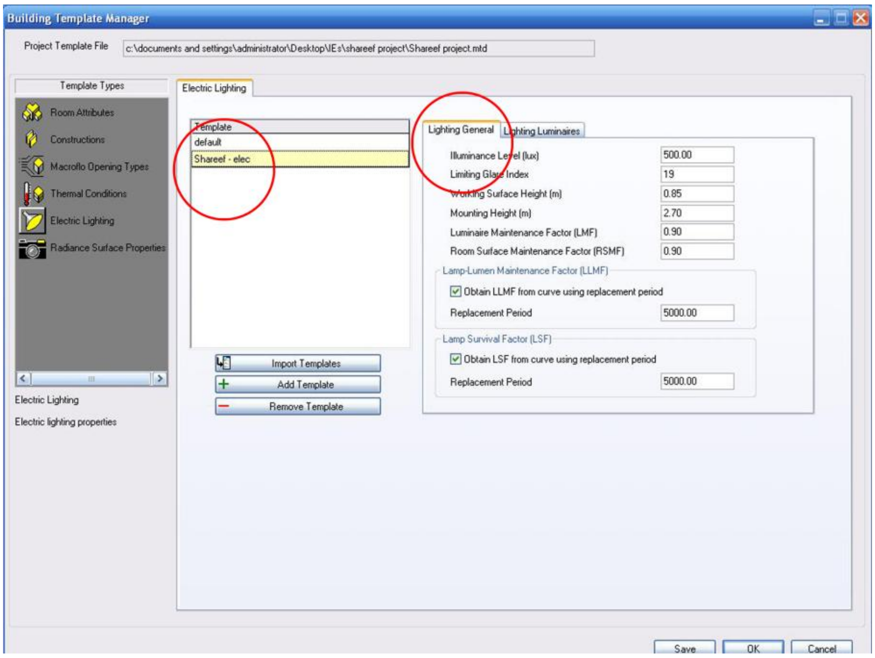



Figure.4.15. Fluorescent lighting system used in simulation. (IES building template manager database).

## 4.5. Office operation time:

The working operation time schedule assumed for the use of office during the week working days (Sunday to Thursday) from 07:00am to 07:00pm, however it's very important for the simulation process to schedule the working hours for the HVAC system, Lighting System and the computers equipment. APpro tools of IES-VE programs allow the user to create different operation profiles for each operating system individually with different operation periods like daily profile, weekly profile and annual profile. In this study three different profiles were created for different operation system. The office lights are modulated to achieve minimum of 500lux from the combined natural daylight and artificial light with daily operation time from 07:00am to 07:00pm during the weekly working days in the first profile as been presented in figure 4.16. The second profile for the computers equipment and people with operation time from 07:00am to 07:00pm during the weekly working days as been presented in figure 4.17. Finally the HVAC system with continuously working operation 24hours during all the week days as Saba tower scenario and usual office towers scenario in Dubai.

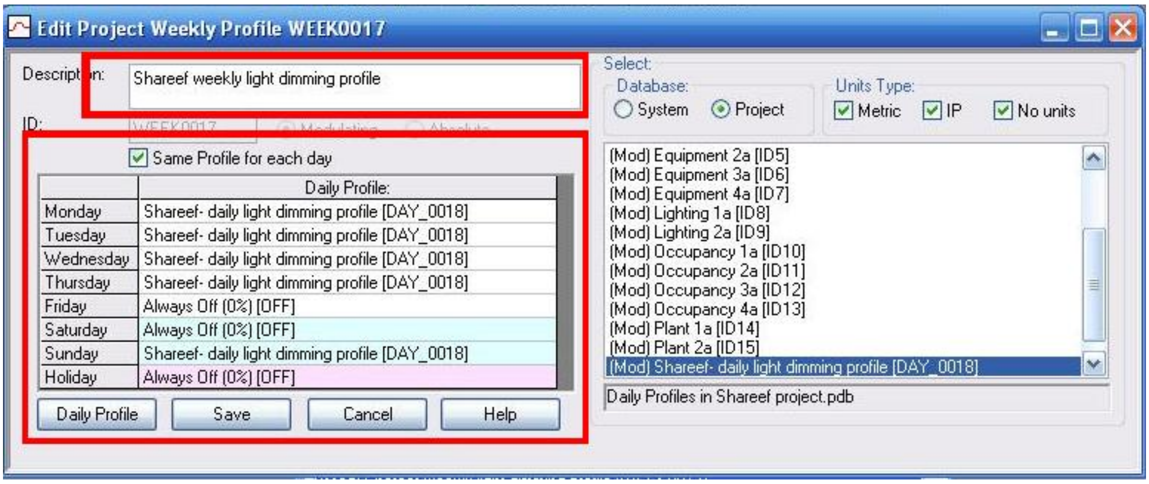



Figure.4.16. Weekly light dimming profile used in simulation. (IES profile database).

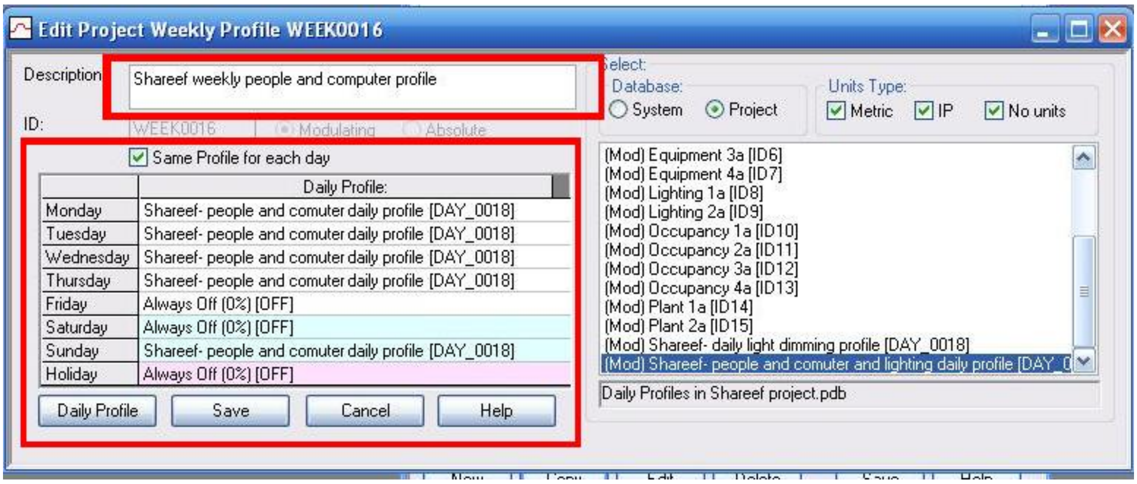



Figure.4.17. Weekly people and computer profile. (IES profile database).

## 4.6. Dubai weather data:

The Dubai city lies between latitudes 25°–25.5°N and longitudes 55°–33°E which is described as the earth's Sun Belt. The subtropical location makes the region hot and humid during the summer months. The humidity is particularly high in the coastal areas. Winter is sunny and warm with some occasional short showers occurring mainly in winter. During summer (April to September) humidity is extremely high particularly in the coastal areas where it can reach to highs of 90%. In winter humidity is less with a range of 30-60. A south western dry, hot and dusty wind comes during summer at an average speed of 25 KM/h. Local north-westerly winds frequently develop during the winter, bringing cooler windy conditions. During summer (June to September) the weather is extremely hot (reaching 50 degrees C). In winter the temperature generally ranges from 20-35 degrees C, with an average night time temperature of 15 degrees C. Wind speed is in the range of 25 to 30Km/h at this time of the year. Rainfall is sparse and intermittent. In most years it rains during the winter months, usually in February or March, but occasionally earlier. Yearly rainfall average is 70 mm.

On the IES-VE program the APlocate is the weather and site location editor for the heat loss and heat gain (ApacheCalc), ASHRAE heat balance method (ApacheLoads), ApachSim, SunCast and Radiance. It is possible to choose a location from an extensive database and guidance is given on defining weather data for various locations. For the purpose of this investigation the Dubai weather database was chosen as a APlocate location in order to select 4 different days representing the 4 different seasons to test the building office energy consumption performance with different external louvers configuration.

## 4.7. Sun path and simulation days:

The subtropical location of Dubai gave high altitude for the sun path for the most of the year as shown in figure 4.18. In summer sun is getting to its highest points in horizon to be nearly perpendicular on June with the longest daytimes when sun rise slightly above the east axis. However in winter the sun located closer to south with shorter path and lower sun angle, the shortest daytimes are on December when the sun rise from the south east direction.

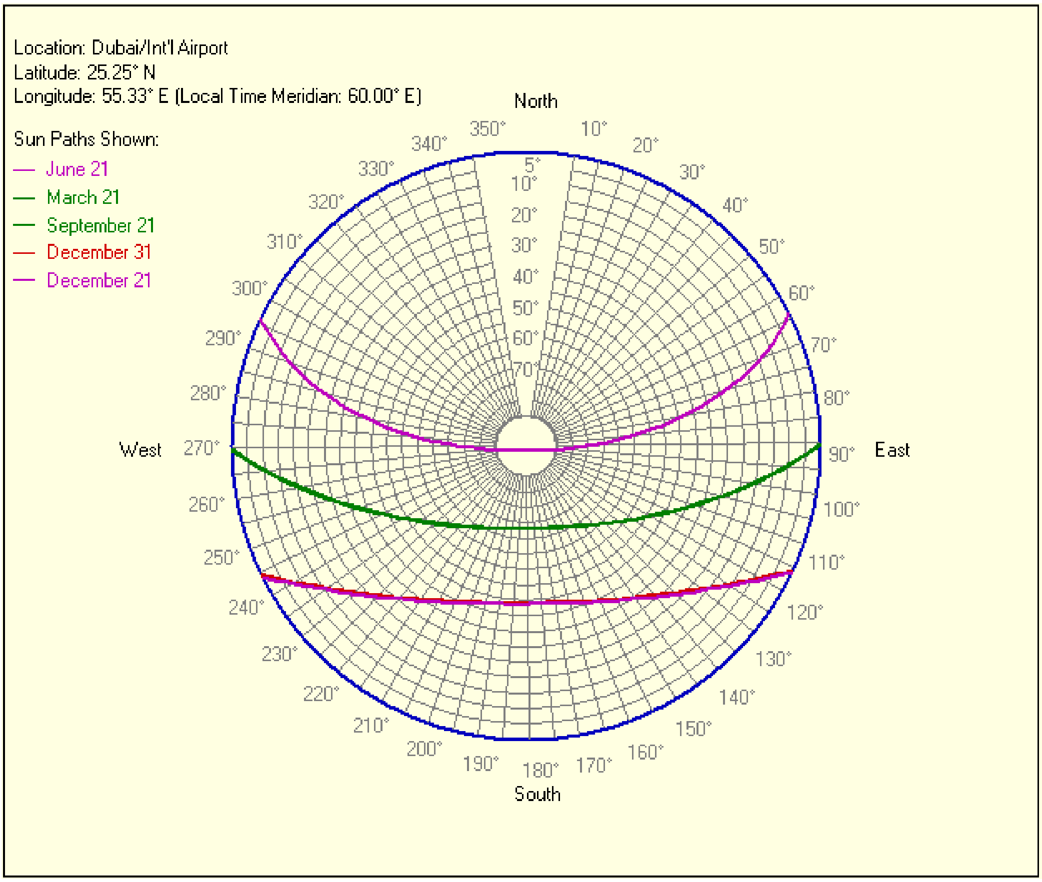



Figure.4.18. Sun path diagram of Dubai. (IES weather database).

As been mentioned 4 different days in 4 different seasons were selected to represent the whole year. These 4 days were selected with the consideration of the latitude seasons, the daily working days (not in weekend) and the atmosphere cloud cover rang such that all the selected days had a clear sky condition. These 4 days are, 21st of March, 20th of June, 20th of September and 15th of December.

- 21st of March:

  In this day as figure 4.19 the maximum dry bulb temperature can reach 32°c and 18°c in minimum, the wet bulb temperature reach 18°c and 13°c in minimum. 6.7m/s the maximum wind speed. As been illustrated in figure 4.20 22%-80% external relative humidity rang with purely clear sky condition. Finally the solar radiation falling can reach 950 Lux (W/m2) as figure 4.21.

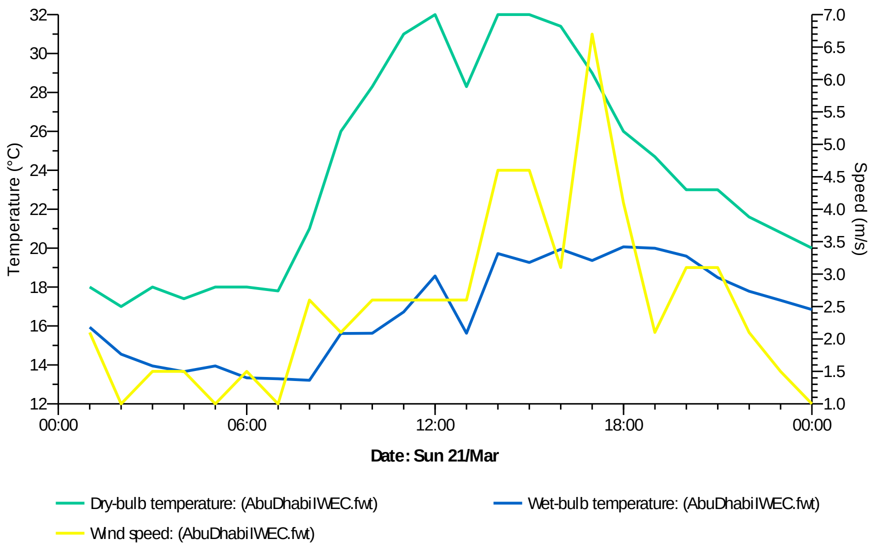



Figure 4.19. Dubai relative temperature and wind speed on Sunday 21st of March. (IES weather database).

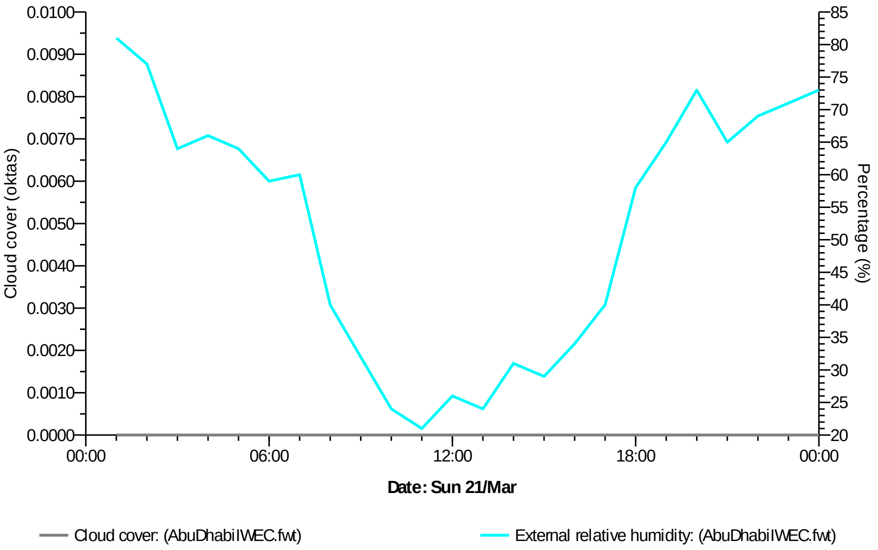



Figure 4.20. Dubai relative humidity and cloud cover on Sunday 21st of March. (IES weather database).

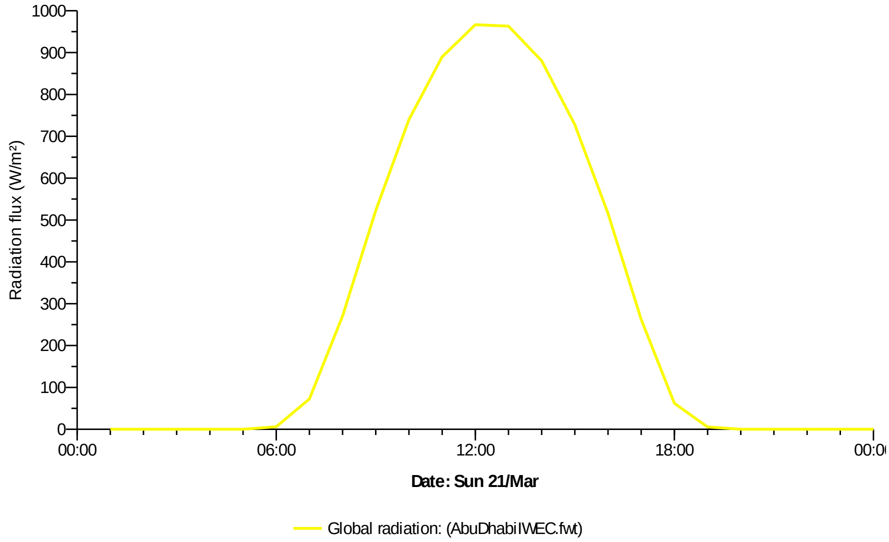



Figure 4.21. Dubai falling solar radiation amount, Sunday 21st of March. (IES weather database).

- 20th of June:

In 20th of June as figure 4.22 the maximum dry bulb temperature can reach 43°c and 25°c in minimum, the wet bulb temperature reach 27°c and 21°c in minimum. 6.2m/s the maximum wind speed. 15%-85% external relative humidity range with purely clear sky condition as figure 4.23. The solar radiation falling can reach 1050 Lux (W/m2) as figure 4.24.

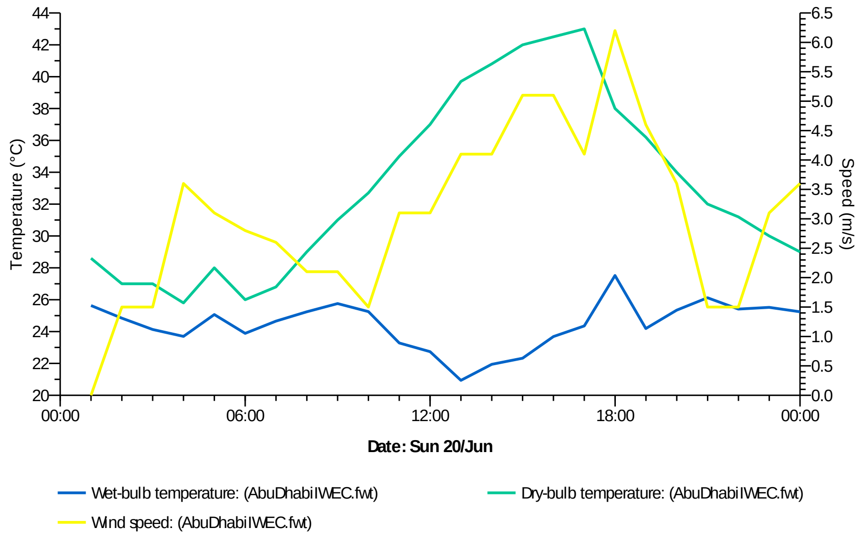



Figure 4.22. Dubai relative temperature and wind speed on Sunday 20th of June. (IES weather database).

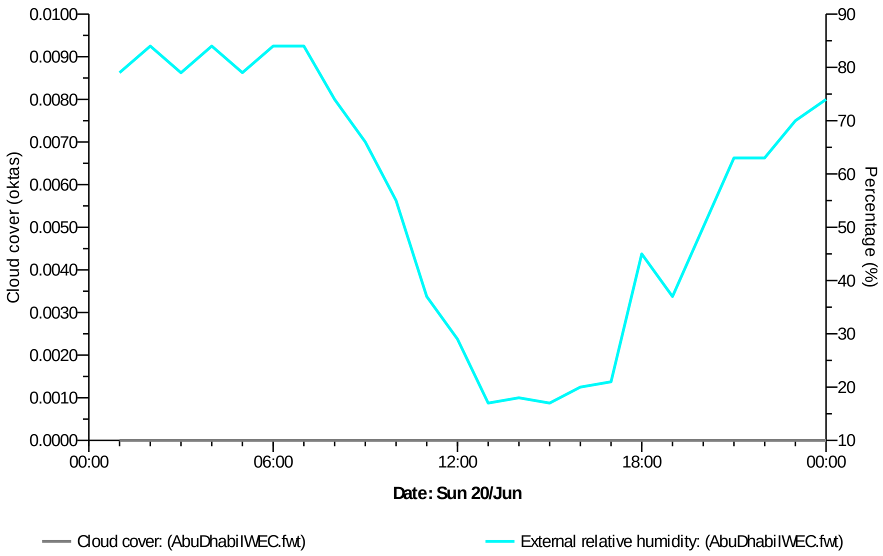



Figure 4.23 Dubai relative humidity and cloud cover on Sunday 20th of June. (IES weather database).

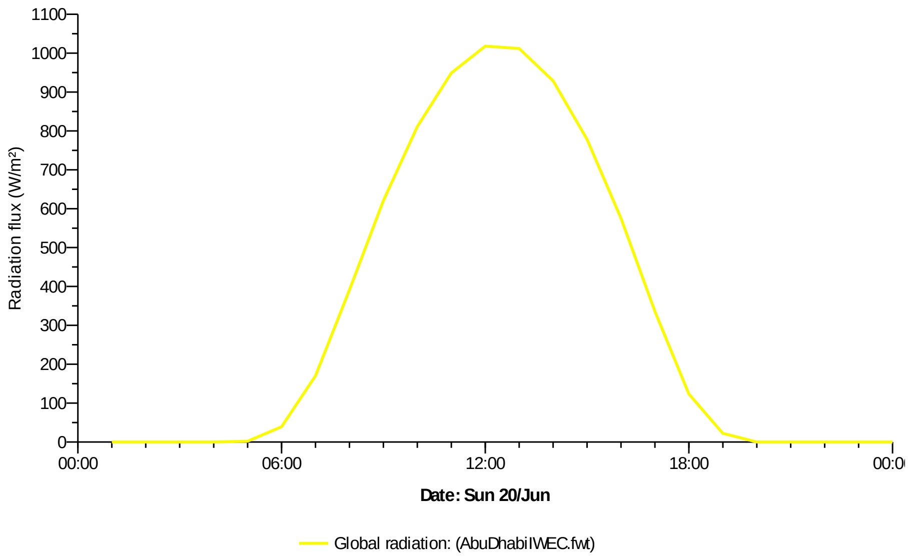



Figure 4.24. Dubai falling solar radiation amount, Sunday 20th of June. (IES weather database).

- 20th of September:

As figure 4.25 the maximum dry bulb temperature can reach 39°c and 26°c in minimum, the wet bulb temperature reach 26°c and 22°c in minimum. 7.5m/s the maximum wind speed. 26%-80% external relative humidity range with purely clear sky condition as figure 4.26. The solar radiation falling can reach 990 Lux (W/m2) as figure 4.27.

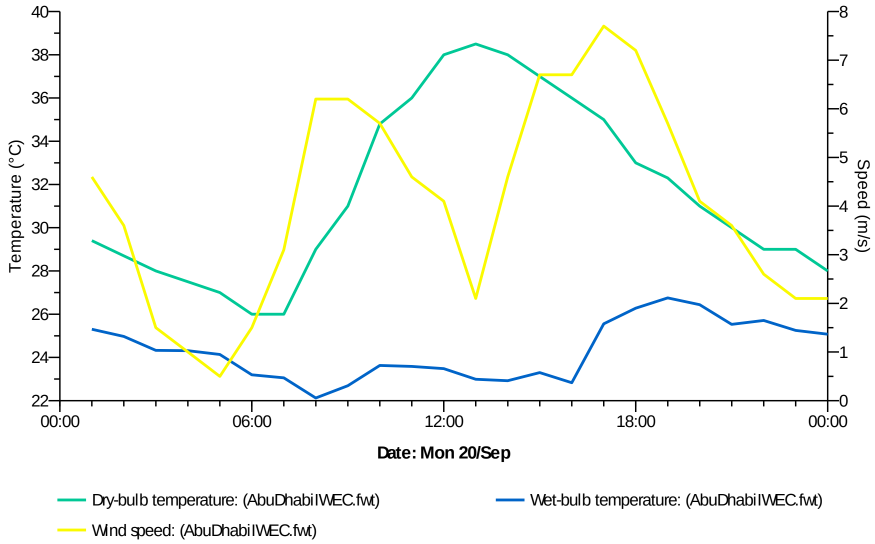



Figure 4.25. Dubai relative temperature and wind speed on Mon 20th of Sep. (IES weather database).

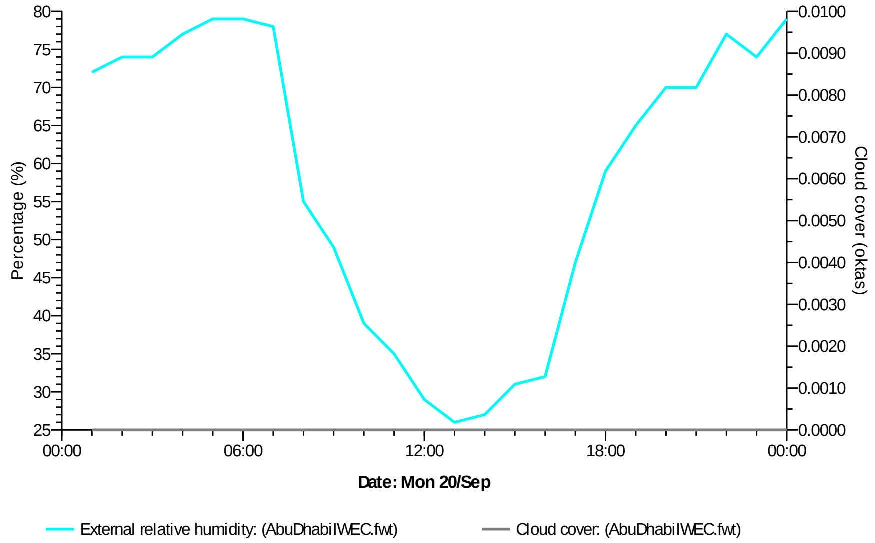



Figure 4.26. Dubai Humidity and cloud cover on Sunday 20th of Sep. (IES weather database).

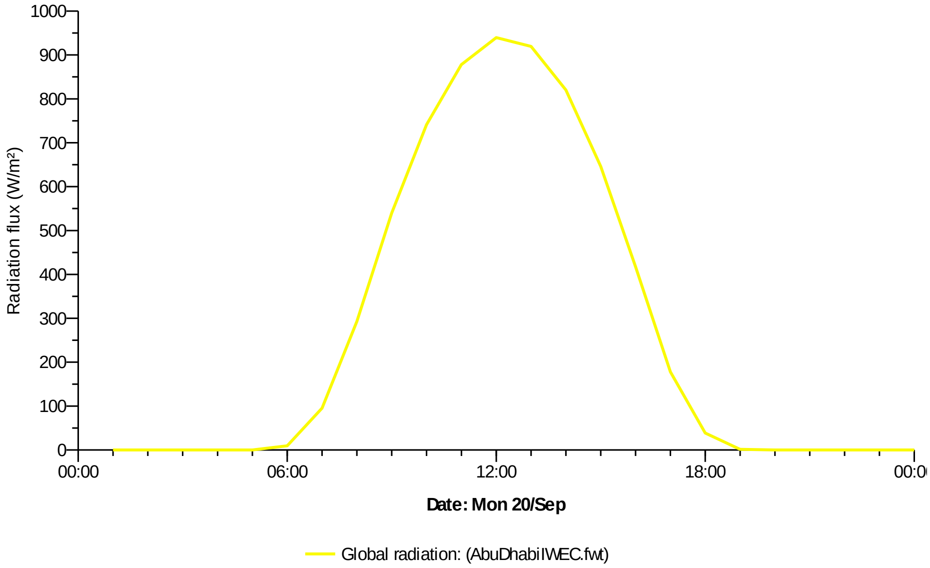



Figure 4.27. Dubai falling solar radiation amount, Mon 20th of Sep. (IES weather database).

- 15th of December:

As figure 4.28 the maximum dry bulb temperature can reach 25°c and 13°c in minimum, the wet bulb temperature reach 18°c and 11°c in minimum. 4.3m/s the maximum wind speed. As figure 4.29 46%-87% external relative humidity range with clear sky condition from 04:00am to 02:00pm, 06:00pm to the end of day and some cloud cover during the others times, however this is the clearest sky condition day in December. The over cast sky during December could reduce the direct solar radiation. The solar radiation falling can reach 700 Lux (W/m2) as figure 4.30.

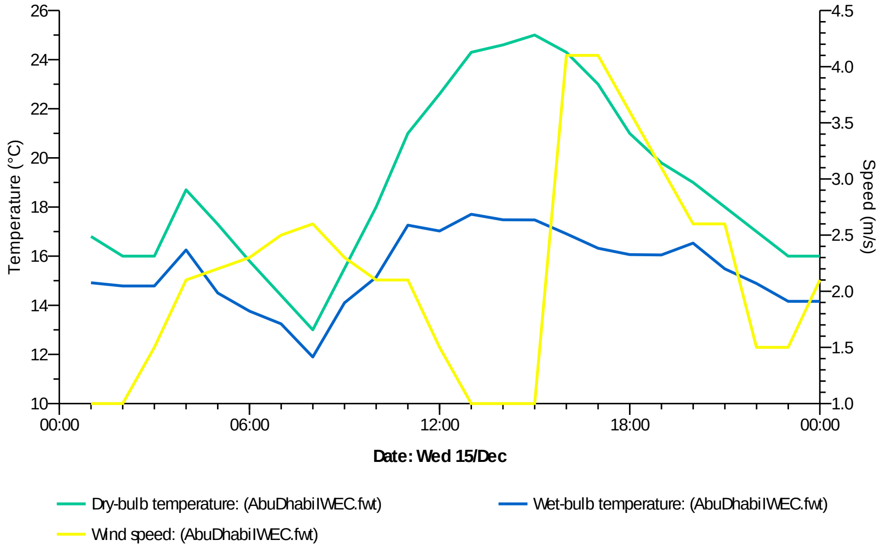



Figure 4.28. Temperature and wind speed on Wed 15st of Dec. (IES weather database).

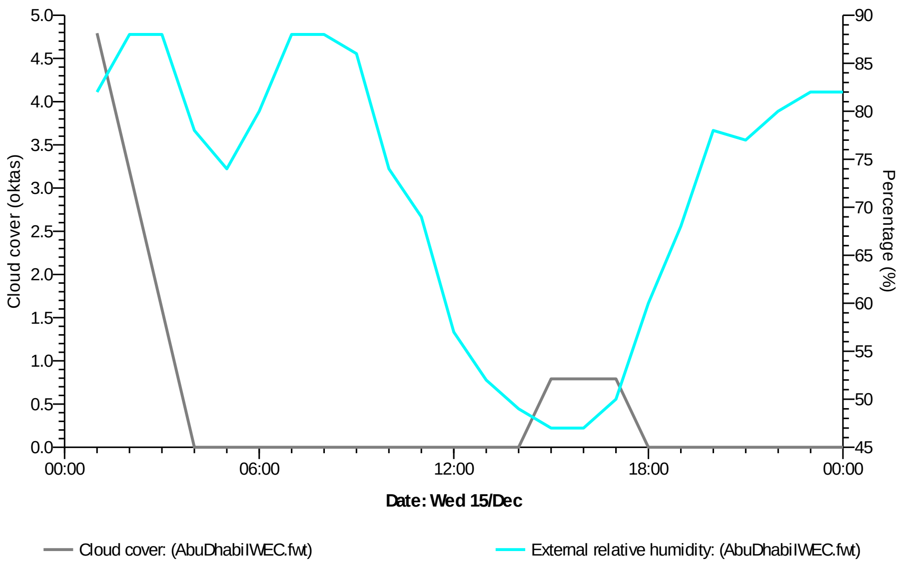



Figure 4.29. Humidity and cloud cover on Wed 15st of Dec. (IES weather database).

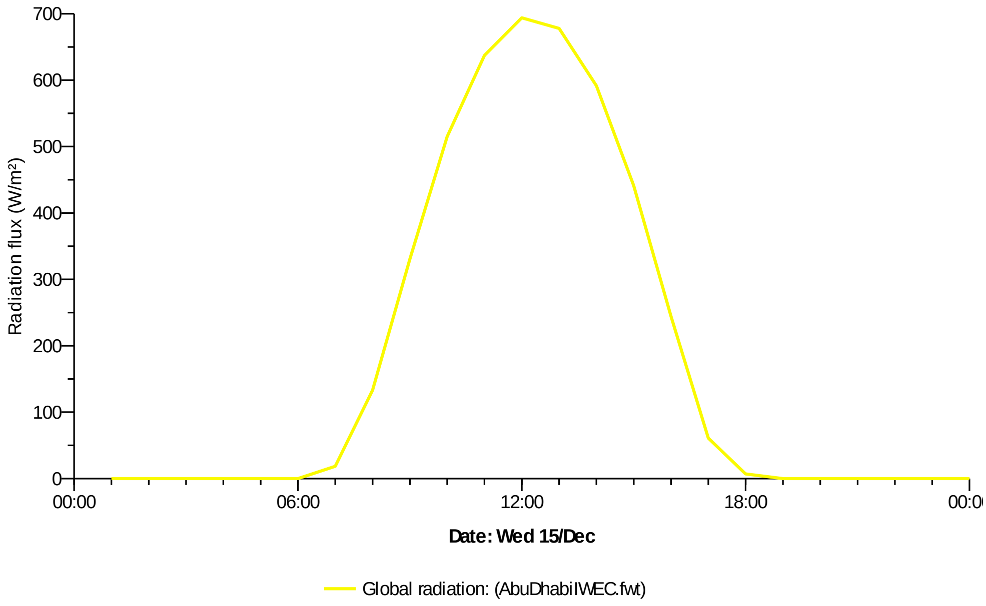



Figure 4.30. Dubai falling solar radiation amount, Wed 15$^{st}$ of Dec. (IES weather database).

## 4.8. Defining the research parameters:

In order to evaluate the efficiency of the optimum design for external fixed lovers shading, some variable will be manipulated in different configurations. Energy consumption cost will be the main outcome of this study. The main variable in this test as the following:

- The Aspect Ratio (AR) between the Louvers Spacing distance (LS) and Louvers Width (LW) with 0° slat angle for all cases, figure 4.31 Illustrate these diminutions in louvers design. Lighting and cooling loads of the interior space are affected by adjusting this ratio due the sun angle and position changes from time to time and form season to season. The four different Aspect Ratio will be tested:
    - AR=1.0 (LW=LS).

- AR=0.5 (2LW=LS).
- AR=2.0 (LW=2LS).
- AR=3.0 (LW=3LS).

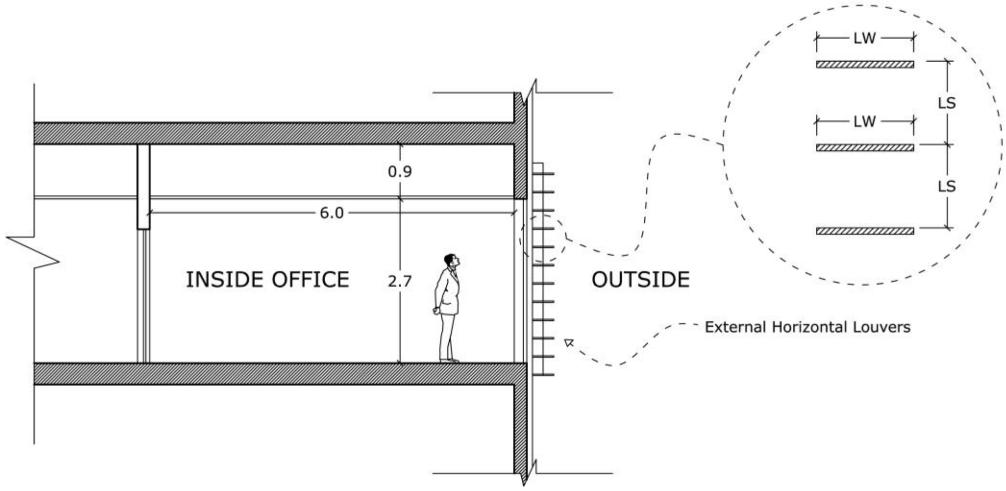



Figure 4.31 The ratio between the louvers spacing distance (LS) and louvers width (LW).

- Orientation: This variable will be tested independently for all configurations. All cases will be examined during the daytime from 7am to 7pm on four different seasons.

- Louvers material: This variable will be tested in two materials colors, (opaque material) with surface reflectance value 0 and (mirror material color) with surface reflectance value 1 compared with the standard materials color with surface reflectance value 0.256. The light color for the louvers material could increase the amount of the reflected diffuse light inside the building which helps to enhance the interior luminance and reduce the produced heat from artificial light. The louvers material test will be for the optimum case of ratio test.

- Louvers slate tilt angle: This variable will be tested in three lovers tilt slat angle 0° (the standard angle case), 20° and 40° with the case louvers ratio AR=1 (LW=LS) for the South orientation only. The selection of these two angles value was considered to keep the visual relation between the inside and outside. Figure 4.32 shows the tested louvers slat tilt angles.

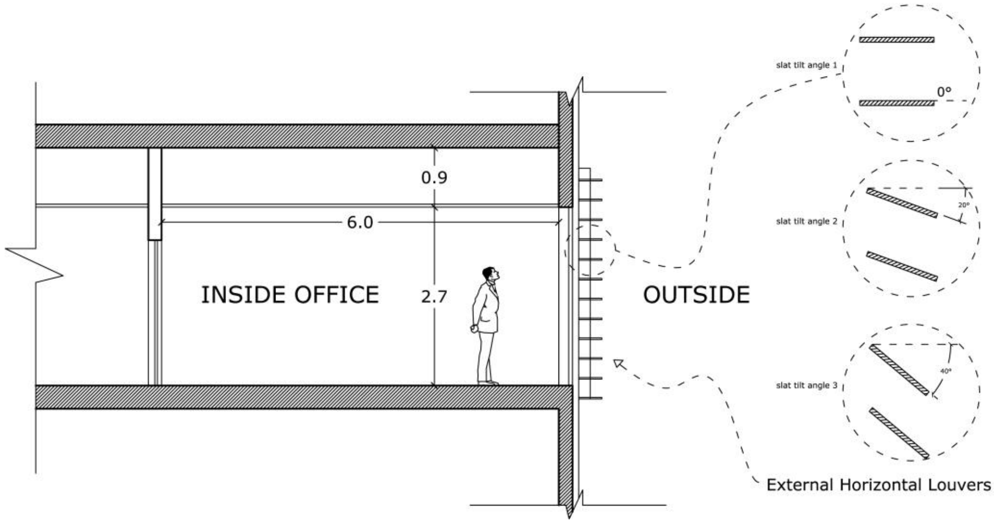



Figure 4.32. Louvers slate tilt angles.

- Louvers with semitransparent materials: This variable will be tested for the South orientation for the louvers ratio AR=1 (LW=LS) and 0° slat tilt angle. The use of semitransparent material could increase the penetrated diffuse lights which help to enhance the interior illuminance. The test will be by using semitransparent material with visible transmittance (VT) 30%, 50% and 75%.

## 4.9. <u>Matrix for simulation cases</u>:

In order to have a comprehensive understanding for the proposed simulation cases of this investigation, Table 4.1 shows the simulation matrix in details as follows:

- Base case simulation: this simulation case will be without shading devices installation and with no lighting dimming control in order to present the current situation in Saba office tower and the most Dubai offices scenario. The running simulation will be for the North, East, West and South façade during the four selected days.

- Light dimming system only: this simulation case will be without shading devices installation but with lighting dimming control system in order to present the energy saving effect of the dimming control system. The running simulation will be for the South façade during September.

- Louvers Aspect Ratio test group: In this simulation group the test will be for the ratio between the louvers spacing distance (LS) and louvers width (LW) with 0° slat angle for all cases as been mentioned before. Four different (AR) will be tested in order to find the optimum design ratio. Lighting and cooling loads of the interior space is affected by adjusting this ratio due the sun angle and position variety from time to time and season to season. The running simulation for all (AR) scenarios will be for the East, West and South façade during the four selected days. The (AR) simulation for the North orientation will be for the standers louvers ratio only, (AR=1). For the standard louvers ratio (AR=1) will be conducted with three different values for (LS): 20cm, 30cm and 40cm. This will be done on south orientation only during one selected day in order to validate the performance results for the same louvers ratio.

- Louvers materials color group: This simulation group will be tested in tow materials color: opaque material and mirror material color. The test in this group will be for the optimum louvers ratio design. The simulation will be for the South orientation only during the four selected days.

- Louvers with slat angle 0° (the standard angle case), 20° and 40° with the case louvers ratio (LW) = (LS) for the South orientation only.
- Semitransparent materials test this for the South orientation with the louvers ratio (LW) = (LS) and 0° slat tilt angle.

Table 4. Matrixes for simulation cases.

| Matrix for Simulation Cases | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Louvers installation with light sensor control, Lighting sensor with 2 meters distance from the window, based on ceiling. | | | | | | | | | | | | | | |
| | Base case | Light sensor control only | Louvers ratio test group with 0° slat angle | | | | | | | Louvers angle test group | | Semitransparent louvers test group for AR = 3.0 with 0° angle. | | | Louvers materials color group with 0° slat angle | |
| | | | AR=1 | | | | AR = 0.5 | AR = 2.0 | AR = 3.0 | AR = 1 with 20° | AR = 1 with 40° | SEMITRANSPARENT MATERIAL WITH VT 30% | SEMITRANSPARENT MATERIAL WITH VT 50% | SEMITRANSPARENT MATERIAL WITH VT 75% | Optimum Louvers ratio with opaque material color | Optimum Louvers ratio with mirror material color |
| | | | LS=10 | LS=20 | LS=30 | | | | | | | | | | | |
| South Façade Simulations | | | | | | | | | | | | | | | | |
| Dec. | X | | | | | X | X | X | X | X | X | X | X | X | X | X |
| Mar. | X | | | | | X | X | X | X | X | X | X | X | X | X | X |
| Jun. | X | | | | | X | X | X | X | X | X | X | X | X | X | X |
| Sep. | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| East Façade Simulation | | | | | | | | | | | | | | | | |
| Dec. | X | | | | | X | X | X | X | | | | | | X | X |
| Marc. | X | | | | | X | X | X | X | | | | | | X | X |
| Jun. | X | | | | | X | X | X | X | | | | | | X | X |
| Sep. | X | | | | | X | X | X | X | | | | | | X | X |
| West Façade Simulation | | | | | | | | | | | | | | | | |
| Dec. | X | | | | | X | X | X | X | | | | | | X | X |
| Mar. | X | | | | | X | X | X | X | | | | | | X | X |
| Jun. | X | | | | | X | X | X | X | | | | | | X | X |
| Sep. | X | | | | | X | X | X | X | | | | | | X | X |
| North Façade Simulation | | | | | | | | | | | | | | | | |
| Dec. | X | | | | | | | | X | | | | | | | |
| Mar. | X | | | | | | | | X | | | | | | | |
| Jun. | X | | | | | | | | X | | | | | | | |
| Sep. | X | | | | | | | | X | | | | | | | |

Finally about this simulation study it's important to note that the analysis for the typical selected office from Saba tower runs without any consideration of the surrounding building and the building site urban shading properties.

## 4.10. Model validation:

The cooling load was simulated for the same model parameters with CARRIER HAP4.2 thermal simulation software by a mechanical engineer in order to verify the results obtained from the base case. IES was used the ASHREA load calculations to obtain the cooling load of the base case during the operations time from 07:00am to 07:00pm in September.

The cooling load by the both tools shows approximately same results with small difference due the different in the used weather data in IES database and CARRIER HAP4.2. Figure 4.33 shows the cooling load by both simulation tools in September during the operation time.

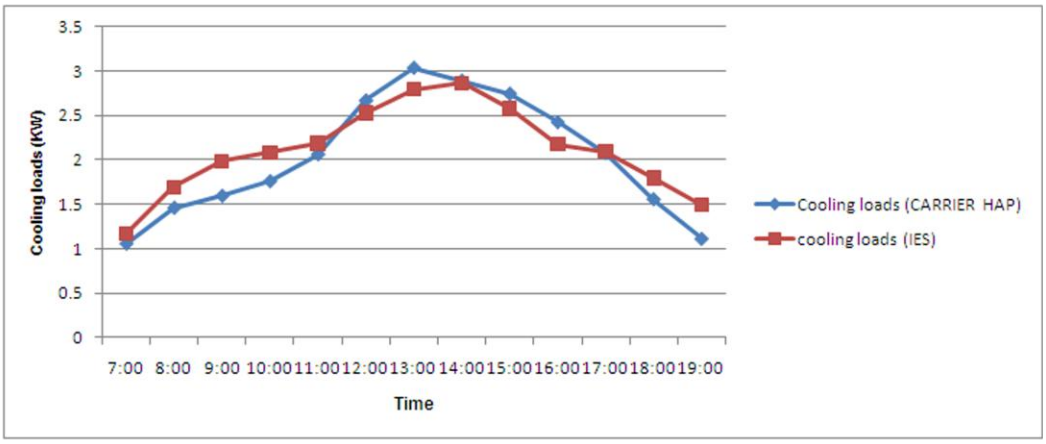



Figure 4.33. CARRIER HAP and IES cooling loads.

# Chapter 5: Simulation Results and Discussion

## 5.1. Introduction:

This chapter describes the simulation results of the parameters identified before. The Simulation test carrying out the simulation runs to check the energy performance of the external louvers shading devices with various louvers properties and configurations as been mentioned in chapter 4. The respective results are summarized for the purpose of comparison and analysis.

## 5.2. Louvers Aspect Ratio results AR = (LW/LS):

It must be noted that the louvers ratio test values runs in order to investigate the energy performance for the louver AR=1 (LS=LW) with different value (LS) = (LW) =10cm, 20cm and 30cm as been illustrated in chapter 4 Table 4.1. The result from figure 5.1 shows that a 98% similarity of energy performance for the three different value. This shows that what is important is the AR not the individual physical length of each of LS and LW. This is important as we can focus on the effect of AR only without having to test the different combination of LS and LW that give similar AR.

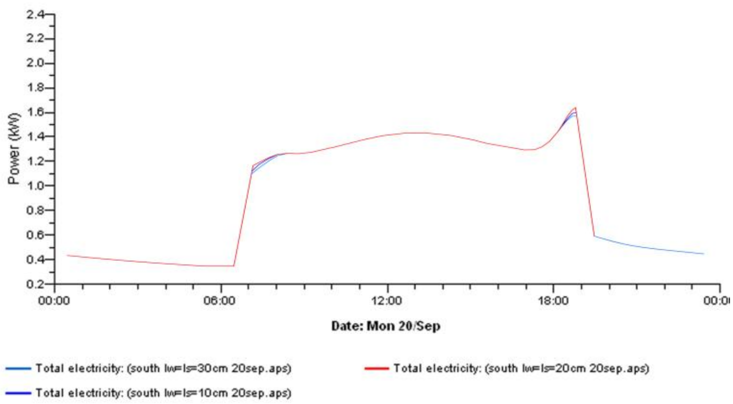



Figure 5.1. Total energy consumptions (KW) for AR=1 with three value of LW= 10cm, 20cm and 30cm for the south orientation on 20th of September.

## 5.3. Energy saving of light dimming system:

The graph in figure 5.2 shows that the light dimming system caused an energy saving reduction of 4.873% compared with the base case for the South orientation. This result presents the weak energy saving efficiency of using the light dimming system only.

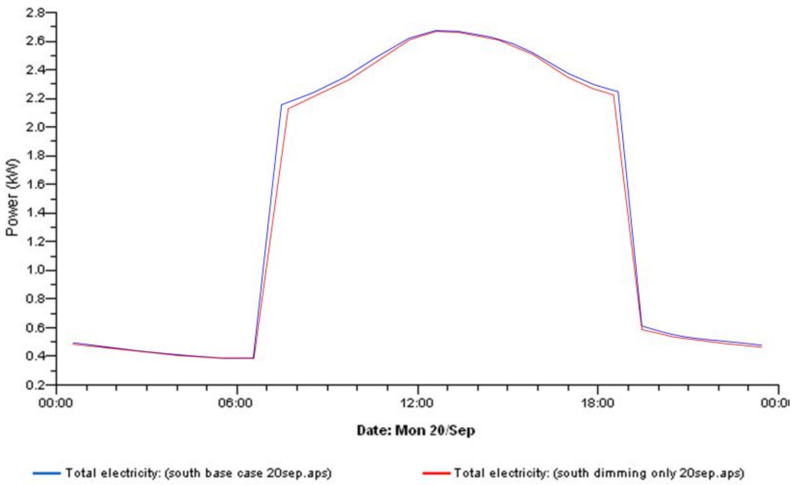



Figure 5.2. Total energy consumptions (KW) for the base case and the light dimming system without louvers shading.

## 5.4. South, North, East and West orientations results:

The results in table 5.1 show for the three orientations that the louvers shading installation with diming lighting control system caused an energy saving with different value according to the louvers configurations and properties during the four selected days. Changing the louvers color from reference to opaque and mirror type resulted in minimal extra energy reduction 0.353% and 0.415% compared to the slandered reference color. This indicates that louvers color is not an important factor to consider in this type of configuration.

For the North orientation scenario the graph in figure 5.3 shows in minimal extra energy reduction 2.09%, 4.59%, 2.27% and 1.93% compared with the base case during March, June, September and December, respectively. This shows that the weak influence of the louvers shading in energy saving for the north orientation. It is observed that the energy saving during March, September and December follow the same trend. On the other hand the maximum energy saving was during June. This different caused due the different in sun path from season to season. However sun facing the north orientation only on June as been presented in figure 4.18 chapter 4.

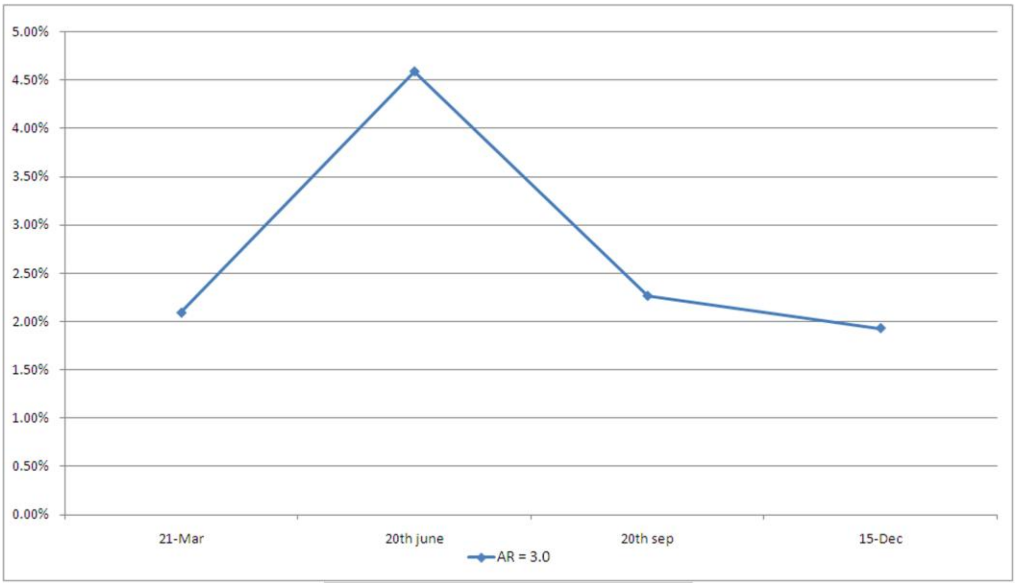



Figure 5.3. Energy saving% compared with the base case for the North orientation with the louver scenario AR=3.0 during the four seasons.

Full simulations data measurements require 12 tables like that shown in Table 5.1 1056 rows of measurements represent the hourly simulations over the course of four seasons. The South, East and West orientations simulations group results are listed as the four selected days 21st of March, 20th of June, 20th of September and 15th of December.

Table 5.1. Excel sheet represent the hourly consumption energy measurements been collected for the South, East and West orientations during the four selected days.

| Date | Time | Energy Consumption For **South** Façade (KW) | | | | | | | | | | Energy Consumption For **East** Façade (KW) | | | | | Energy Consumption For **West** Façade (KW) | | | | | Energy Con- For **North** Façade (KW) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Base Case | AR = 0.5 | AR = 1.0 | AR = 2.0 | AR = 3.0 | AR = 1.0 with 20° | AR = 1.0 with 40° | AR = 3.0 semi- VT 30% | AR = 3.0 semi- VT 50% | AR = 3.0 semi- VT 75% | Base Case | AR = 0.5 | AR = 1.0 | AR = 2.0 | AR = 3.0 | Base Case | AR = 0.5 | AR = 1.0 | AR = 2.0 | AR = 3.0 | Base Case | AR = 1.0 |
| 21st of March | 7:00 | 1.1567 | 1.0376 | 0.9121 | 0.9546 | 0.8935 | 0.9735 | 0.9987 | 0.9135 | 0.8847 | 0.8947 | 1.1524 | 1.0167 | 0.9156 | 0.9127 | 0.8156 | 1.2316 | 1.2325 | 1.2323 | 1.2354 | 1.2341 | 1.0356 | 1.1106 |
| | 8:00 | 1.6745 | 1.3154 | 1.1643 | 1.0945 | 1.0365 | 1.1267 | 1.1845 | 0.9926 | 0.9732 | 1.0237 | 2.3167 | 1.5827 | 1.3846 | 1.2836 | 0.1235 | 1.9846 | 1.9135 | 1.8635 | 1.8548 | 1.8524 | 1.7151 | 1.6625 |
| | 9:00 | 1.7798 | 1.4265 | 1.2343 | 1.1846 | 1.1145 | 1.1925 | 1.2645 | 1.0634 | 1.0543 | 1.0935 | 2.5314 | 2.0625 | 1.6537 | 1.5326 | 1.3265 | 2.0126 | 1.9536 | 1.9156 | 1.8726 | 1.8425 | 1.8547 | 1.8247 |
| | 10:00 | 1.8456 | 1.5212 | 1.3174 | 1.2574 | 1.1634 | 1.2835 | 1.3464 | 1.1398 | 1.0954 | 1.1316 | 2.5715 | 2.1936 | 1.8726 | 1.7527 | 1.5134 | 2.0836 | 1.9726 | 1.9465 | 1.8967 | 1.8736 | 1.9621 | 1.9289 |
| | 11:00 | 1.8867 | 1.61445 | 1.3834 | 1.2946 | 1.2213 | 1.3576 | 1.4213 | 1.1839 | 1.1703 | 1.2138 | 2.4725 | 2.2267 | 1.9537 | 1.8527 | 1.6325 | 2.0927 | 2.0167 | 1.9726 | 1.9326 | 1.8825 | 2.0348 | 2.0201 |
| | 12:00 | 1.9423 | 1.6823 | 1.4737 | 1.3487 | 1.2623 | 1.3835 | 1.4852 | 1.2265 | 1.1965 | 1.2645 | 2.2917 | 2.1624 | 1.9534 | 1.8726 | 1.7156 | 2.1236 | 2.0214 | 1.9827 | 1.9526 | 1.9223 | 2.0739 | 2.0425 |
| | 13:00 | 1.9712 | 1.7176 | 1.5267 | 1.3836 | 1.3114 | 1.4527 | 1.5593 | 1.2375 | 1.2265 | 1.2749 | 2.1935 | 2.0917 | 1.9927 | 1.9837 | 1.8524 | 2.1537 | 2.0615 | 1.9736 | 1.8937 | 1.8256 | 2.0876 | 2.0534 |
| | 14:00 | 2.0123 | 1.7523 | 1.5748 | 1.4325 | 1.3564 | 1.5143 | 1.5724 | 1.2436 | 1.2157 | 1.2701 | 2.1762 | 2.0826 | 2.0325 | 2.0167 | 1.9827 | 2.2436 | 2.1153 | 1.8936 | 1.8123 | 1.6537 | 2.0905 | 2.0852 |
| | 15:00 | 2.0243 | 1.7724 | 1.5823 | 1.4576 | 1.3618 | 1.5386 | 1.5746 | 1.2574 | 1.2345 | 1.265 | 2.1536 | 2.0726 | 2.0236 | 1.9726 | 1.9276 | 2.3927 | 2.1537 | 1.8736 | 1.7837 | 1.5938 | 2.1237 | 2.1027 |
| | 16:00 | 1.9934 | 1.7668 | 1.5579 | 1.4476 | 1.3517 | 1.5234 | 1.5784 | 1.2893 | 1.2567 | 1.3257 | 2.1176 | 2.0256 | 1.9827 | 1.9527 | 1.9134 | 2.5473 | 2.1234 | 1.8167 | 1.6836 | 1.4738 | 2.0958 | 2.0673 |
| | 17:00 | 1.9645 | 1.7323 | 1.5267 | 1.4427 | 1.3642 | 1.4853 | 1.5594 | 1.3275 | 1.3122 | 1.3759 | 2.0725 | 1.9876 | 1.9726 | 1.9426 | 1.8836 | 2.5145 | 2.0527 | 1.6127 | 1.5234 | 1.2871 | 2.0645 | 2.0356 |
| | 18:00 | 1.8723 | 1.6823 | 1.5123 | 1.4365 | 1.3725 | 1.4463 | 1.5256 | 1.3382 | 1.3205 | 1.3648 | 2.0256 | 1.9537 | 1.9236 | 1.9117 | 1.8928 | 2.3176 | 1.5826 | 1.3526 | 1.2514 | 1.0927 | 2.0136 | 1.9642 |
| | 19:00 | 1.4198 | 1.4787 | 1.4812 | 1.3834 | 1.3587 | 1.4365 | 1.4587 | 1.3378 | 1.3326 | 1.3466 | 1.4526 | 1.4526 | 1.4524 | 1.4526 | 1.4527 | 1.3547 | 1.1186 | 0.9827 | 0.9716 | 0.8526 | 1.2769 | 1.0205 |
| Total | | 23.5434 | 20.49985 | 18.2471 | 17.1183 | 16.1682 | 17.7144 | 18.529 | 15.551 | 15.2731 | 15.8448 | 27.5278 | 24.911 | 23.1137 | 22.4395 | 20.0323 | 27.0528 | 24.3181 | 22.4187 | 21.6644 | 20.3867 | 24.4288 | 23.9182 |
| Energy saving % | | | 12.93% | 22.50% | 27.29% | 31.33% | 24.76% | 21.30% | 33.95% | 35.13% | 32.70% | | 9.51% | 16.04% | 18.48% | 27.23% | | 10.11% | 17.13% | 19.92% | 24.64% | | 2.09% |
| 20th of June | 7:00 | 1.2176 | 1.0857 | 1.0856 | 1.0156 | 1.0528 | 0.9846 | 1.0548 | 0.9564 | 0.9414 | 0.9514 | 1.1726 | 1.0526 | 0.9856 | 0.9539 | 0.9256 | 1.1375 | 1.1527 | 1.1376 | 1.1325 | 1.1375 | 1.2704 | 1.0863 |
| | 8:00 | 2.0245 | 1.8256 | 1.7846 | 1.7365 | 1.6864 | 1.7846 | 1.7937 | 1.6722 | 1.6202 | 1.6602 | 2.5326 | 1.7927 | 0.4937 | 1.2937 | 1.2167 | 2.0167 | 1.9167 | 1.8937 | 1.8726 | 1.8537 | 2.1453 | 2.0271 |
| | 9:00 | 2.1156 | 1.8846 | 1.8456 | 1.7856 | 1.7537 | 1.8267 | 1.8456 | 1.7156 | 1.7126 | 1.7126 | 2.8436 | 2.1354 | 1.7326 | 1.5243 | 1.4256 | 2.0827 | 1.9726 | 1.9245 | 1.9167 | 1.8735 | 2.1942 | 2.0561 |
| | 10:00 | 2.1754 | 1.9635 | 1.8826 | 1.8354 | 1.7937 | 1.8426 | 1.9256 | 1.7426 | 1.7306 | 1.7306 | 2.9167 | 2.2167 | 1.8837 | 1.6937 | 1.5825 | 2.1365 | 2.0178 | 1.9836 | 1.9526 | 1.8937 | 2.2356 | 2.0964 |
| | 11:00 | 2.2435 | 2.0265 | 1.9735 | 1.8867 | 1.8536 | 1.9427 | 1.9725 | 1.7835 | 1.7725 | 1.7725 | 2.7415 | 2.2134 | 1.9367 | 1.7726 | 1.6536 | 2.2123 | 2.0837 | 2.0716 | 2.0256 | 1.9365 | 2.2507 | 2.1806 |
| | 12:00 | 2.2745 | 2.0715 | 2.0237 | 1.9324 | 1.8736 | 1.9836 | 2.0327 | 1.7925 | 1.7905 | 1.7905 | 2.4928 | 2.2265 | 2.0267 | 1.7927 | 1.6927 | 2.2925 | 2.2278 | 2.1829 | 2.1378 | 2.0738 | 2.2638 | 2.1925 |
| | 13:00 | 2.2835 | 2.0916 | 2.0376 | 1.9465 | 1.8735 | 1.9836 | 2.0267 | 1.8265 | 1.8245 | 1.8245 | 2.3917 | 2.3256 | 2.2967 | 1.9637 | 1.7435 | 2.4145 | 2.2545 | 2.2134 | 2.1536 | 1.6839 | 2.2815 | 2.2206 |
| | 14:00 | 2.2957 | 2.1183 | 2.0167 | 1.9576 | 1.8834 | 1.9826 | 2.0267 | 1.8167 | 1.8127 | 1.8127 | 2.3728 | 2.2917 | 2.2567 | 2.1927 | 2.1563 | 2.5538 | 2.1919 | 1.9827 | 1.8356 | 1.6313 | 2.2768 | 2.2304 |
| | 15:00 | 2.2786 | 2.0846 | 2.0176 | 1.9638 | 1.8956 | 1.9735 | 2.0156 | 1.7845 | 1.7815 | 1.7815 | 2.3562 | 2.2871 | 2.2145 | 2.1945 | 2.1325 | 2.7527 | 2.1837 | 1.9726 | 1.7839 | 1.5837 | 2.3204 | 2.2795 |
| | 16:00 | 2.2537 | 2.0715 | 1.9936 | 1.9364 | 1.8826 | 1.9634 | 2.0216 | 1.7936 | 1.7906 | 1.7906 | 2.3526 | 2.2687 | 2.1963 | 2.1476 | 2.1153 | 2.7928 | 2.1738 | 1.8938 | 1.6838 | 1.5132 | 2.3547 | 2.2637 |
| | 17:00 | 2.2235 | 2.0635 | 1.9845 | 1.9156 | 1.8645 | 1.9735 | 2.0245 | 1.8143 | 1.8113 | 1.8113 | 2.3573 | 2.2376 | 2.1927 | 2.1523 | 2.1163 | 2.6728 | 2.0537 | 1.6927 | 1.5526 | 1.4256 | 2.3671 | 2.2149 |
| | 18:00 | 2.1523 | 2.0635 | 1.9746 | 1.8905 | 1.8573 | 1.9746 | 1.9807 | 1.8225 | 1.8115 | 1.8215 | 2.3365 | 2.2376 | 2.2176 | 2.1826 | 2.1536 | 2.4387 | 1.7529 | 1.5837 | 1.4537 | 1.3527 | 2.3105 | 2.1506 |
| | 19:00 | 1.4123 | 1.4136 | 1.4154 | 1.4167 | 1.4156 | 1.4164 | 1.4127 | 1.4134 | 1.4134 | 1.4234 | 1.4937 | 1.5176 | 1.5145 | 1.5134 | 1.5154 | 0.3527 | 1.3526 | 1.3312 | 1.3327 | 1.3326 | 1.4658 | 1.4652 |
| Total | | 26.9507 | 24.764 | 24.0356 | 23.2193 | 22.6863 | 23.6324 | 24.1334 | 21.9343 | 21.8133 | 21.8833 | 30.3606 | 26.8032 | 23.948 | 23.3777 | 22.4296 | 27.8562 | 25.3344 | 23.864 | 22.8337 | 21.2917 | 27.7368 | 26.4639 |
| Energy Saving % | | | 8.11% | 10.82% | 13.85% | 15.82% | 12.31% | 10.45% | 18.61% | 19.06% | 18.80% | | 11.72% | 21.12% | 23.00% | 26.12% | | 9.05% | 14.33% | 18.03% | 23.57% | | 4.59% |
| 20th of September | 7:00 | 1.1646 | 1.0537 | 1.0367 | 0.8526 | 0.8736 | 0.8635 | 0.8635 | 0.8636 | 0.8754 | 0.9349 | 1.2156 | 1.0376 | 0.9637 | 0.9423 | 0.9426 | 1.1635 | 1.228 | 1.0118 | 1.0129 | 1.0167 | 1.1736 | 1.0163 |
| | 8:00 | 1.8967 | 1.3378 | 1.2725 | 1.2154 | 1.1836 | 1.2187 | 1.2856 | 1.1637 | 1.1329 | 1.1805 | 2.3625 | 1.7927 | 1.6156 | 1.5234 | 1.3524 | 2.0327 | 1.9539 | 1.9138 | 1.8739 | 1.8326 | 2.0149 | 1.9753 |
| | 9:00 | 1.9845 | 1.3827 | 1.2826 | 1.2315 | 1.1738 | 1.2524 | 2.3278 | 1.1626 | 1.1145 | 1.1709 | 2.5726 | 2.0927 | 1.7738 | 1.6354 | 1.4256 | 2.0828 | 1.9938 | 1.9736 | 1.9128 | 1.8645 | 2.0834 | 2.0548 |
| | 10:00 | 2.0856 | 1.4876 | 1.3327 | 1.2687 | 1.1937 | 1.2927 | 1.3625 | 1.1637 | 1.1285 | 1.1745 | 2.6524 | 2.2376 | 1.8947 | 1.7725 | 1.5326 | 2.1628 | 2.0839 | 2.0249 | 1.9839 | 1.8826 | 2.1748 | 2.1358 |
| | 11:00 | 2.1845 | 1.5872 | 1.3829 | 1.2716 | 1.1947 | 1.3414 | 1.4234 | 1.1738 | 1.1356 | 1.1938 | 2.5926 | 2.2716 | 1.9537 | 1.8635 | 1.6453 | 2.2237 | 2.1317 | 2.0829 | 2.0529 | 1.9524 | 2.1959 | 2.1776 |
| | 12:00 | 2.2716 | 1.6425 | 1.4325 | 1.2911 | 1.2287 | 1.3625 | 1.4628 | 1.1627 | 1.132 | 1.1761 | 2.4526 | 2.2343 | 2.0536 | 1.9725 | 1.6927 | 2.2917 | 2.2116 | 2.1418 | 2.0643 | 1.9927 | 2.2504 | 2.2254 |
| | 13:00 | 2.2916 | 1.6425 | 1.4527 | 1.2876 | 1.2026 | 1.3845 | 1.4875 | 1.1638 | 1.1248 | 1.1866 | 2.3315 | 2.2234 | 2.1836 | 2.0936 | 1.8647 | 2.3849 | 2.2739 | 2.1829 | 2.0534 | 2.0166 | 2.2615 | 2.2349 |
| | 14:00 | 2.2876 | 1.6112 | 1.44276 | 1.2765 | 1.2037 | 1.3825 | 1.4728 | 1.1738 | 1.1135 | 1.1704 | 2.3241 | 2.2165 | 2.1716 | 2.1427 | 2.0927 | 2.6628 | 2.2239 | 1.9829 | 1.8256 | 1.7356 | 2.2583 | 2.2307 |
| | 15:00 | 2.2463 | 1.5524 | 1.3965 | 1.2546 | 1.1826 | 1.3526 | 1.4527 | 1.1424 | 1.1242 | 1.1682 | 2.3144 | 2.1936 | 2.1638 | 2.1426 | 2.0736 | 2.7228 | 2.2429 | 1.8929 | 1.8156 | 1.6927 | 2.2427 | 2.2178 |
| | 16:00 | 2.1538 | 1.5517 | 1.3572 | 1.2254 | 1.1738 | 1.3165 | 1.3827 | 1.1711 | 1.1369 | 1.1741 | 2.2826 | 2.1873 | 2.1538 | 2.1156 | 2.0527 | 2.8537 | 2.2349 | 1.8949 | 1.7726 | 1.6528 | 2.2261 | 2.1956 |
| | 17:00 | 2.0527 | 1.5518 | 1.3276 | 1.2278 | 1.2036 | 1.2836 | 1.3527 | 1.1825 | 1.1461 | 1.1932 | 2.2514 | 2.1735 | 2.1365 | 2.0938 | 2.0327 | 2.7129 | 2.1346 | 1.8329 | 1.7234 | 1.5534 | 2.1973 | 2.1746 |
| | 18:00 | 1.9736 | 1.6618 | 1.3926 | 1.3571 | 1.4536 | 1.3926 | 1.4136 | 1.3956 | 1.2807 | 1.3593 | 2.2415 | 2.1543 | 2.1165 | 2.0836 | 2.0517 | 2.4248 | 1.8518 | 1.6939 | 1.5234 | 1.3827 | 2.1748 | 2.1547 |
| | 19:00 | 1.4526 | 1.4572 | 1.4145 | 1.4146 | 1.5527 | 1.4156 | 1.4134 | 1.5124 | 1.4525 | 1.5104 | 1.4928 | 1.5426 | 1.4256 | 1.5248 | 1.5327 | 1.4147 | 1.5627 | 1.4328 | 1.3526 | 1.3328 | 1.4346 | 1.2903 |
| Total | | 26.0457 | 19.5201 | 17.5238 | 16.1745 | 15.8207 | 16.8591 | 18.701 | 15.4317 | 14.8976 | 15.5929 | 29.0866 | 26.3577 | 24.6065 | 23.9063 | 22.292 | 29.1338 | 26.1276 | 24.062 | 22.9673 | 21.9081 | 26.6883 | 26.0838 |
| Enargy Saving % | | | 25.05% | 32.72% | 37.90% | 39.26% | 35.27% | 28.20% | 40.75% | 42.80% | 40.13% | | 9.38% | 15.40% | 17.81% | 23.36% | | 10.32% | 17.41% | 21.17% | 24.80% | | 2.27% |
| 15th of December | 7:00 | 1.1736 | 0.8946 | 0.8926 | 0.8946 | 0.8937 | 1.9178 | 0.9537 | 0.9156 | 0.8802 | 0.8603 | 1.1537 | 0.9927 | 0.8946 | 0.8847 | 0.7927 | 1.1529 | 1.0329 | 1.0238 | 0.9529 | 0.9528 | 0.8745 | 0.7905 |
| | 8:00 | 1.6836 | 1.3387 | 1.1836 | 1.1964 | 1.0536 | 1.1536 | 1.1836 | 1.0178 | 0.9815 | 1.0634 | 2.2817 | 1.5245 | 1.2947 | 1.1938 | 1.0356 | 1.7228 | 1.6329 | 1.5928 | 1.5729 | 1.5328 | 1.4563 | 1.4276 |
| | 9:00 | 1.7836 | 1.4326 | 1.2436 | 1.2638 | 1.1537 | 1.2267 | 1.2752 | 1.0836 | 1.0804 | 1.1257 | 2.4826 | 1.9354 | 1.6837 | 1.5137 | 1.3156 | 1.8728 | 1.7939 | 1.7639 | 1.6929 | 1.6728 | 1.5802 | 1.5526 |
| | 10:00 | 1.8826 | 1.5248 | 1.3256 | 1.3145 | 1.1836 | 1.2894 | 1.3576 | 1.1367 | 1.0947 | 1.1565 | 2.4926 | 0.1345 | 1.9153 | 1.7346 | 1.5245 | 1.9828 | 1.9239 | 1.8929 | 1.8339 | 1.8128 | 1.6828 | 1.6762 |
| | 11:00 | 1.9227 | 1.5826 | 1.3927 | 1.3417 | 1.2278 | 1.3628 | 1.4226 | 1.1637 | 1.1537 | 1.1903 | 2.4327 | 2.1937 | 1.9917 | 1.8436 | 1.6926 | 2.0328 | 1.9639 | 1.9328 | 1.8939 | 1.8928 | 1.7706 | 1.7539 |
| | 12:00 | 1.9352 | 1.6537 | 1.4717 | 1.3527 | 1.2674 | 1.4326 | 1.4926 | 1.2365 | 1.1862 | 1.2657 | 2.3416 | 2.1847 | 1.9827 | 1.9123 | 1.7736 | 2.0929 | 2.0129 | 1.9428 | 1.9128 | 1.8928 | 1.8348 | 1.8204 |
| | 13:00 | 1.9826 | 1.6827 | 1.5354 | 1.3927 | 1.3243 | 1.4726 | 1.5726 | 1.2635 | 1.2379 | 1.2902 | 2.2936 | 2.2123 | 2.0428 | 2.0123 | 1.9256 | 2.2229 | 2.1729 | 2.0549 | 1.9828 | 1.9129 | 1.8852 | 1.8782 |
| | 14:00 | 2.0187 | 1.7245 | 1.5726 | 1.4378 | 1.3367 | 1.4927 | 1.5827 | 1.2715 | 1.2406 | 1.2835 | 2.2243 | 2.1735 | 2.1178 | 2.0938 | 2.0167 | 2.5338 | 2.0739 | 1.9239 | 1.8528 | 1.7129 | 1.8946 | 1.8825 |
| | 15:00 | 2.0367 | 1.7625 | 1.5839 | 1.4628 | 1.3527 | 1.4826 | 1.5946 | 1.2436 | 1.2347 | 1.2706 | 2.1835 | 2.1142 | 2.0845 | 2.0217 | 1.9847 | 2.4239 | 2.0839 | 1.8939 | 1.7838 | 1.6338 | 1.8704 | 1.8654 |
| | 16:00 | 1.9836 | 1.7536 | 1.571 | 1.4537 | 1.3527 | 1.4826 | 1.5824 | 1.2564 | 1.2548 | 1.2945 | 2.1354 | 2.0346 | 1.9935 | 1.9736 | 1.9138 | 2.3829 | 2.0739 | 1.8828 | 1.7629 | 1.5839 | 1.8336 | 1.8262 |
| | 17:00 | 1.8837 | 1.7254 | 1.5428 | 1.4236 | 1.3426 | 1.4726 | 1.5638 | 1.2736 | 1.2662 | 1.2807 | 2.0725 | 2.9825 | 1.9243 | 1.9176 | 1.8426 | 2.3349 | 1.9538 | 1.8118 | 1.6719 | 1.5239 | 1.7802 | 1.7705 |
| | 18:00 | 1.8376 | 1.6836 | 1.5178 | 1.4236 | 1.3331 | 1.4726 | 1.5256 | 1.2716 | 1.2506 | 1.2738 | 1.9925 | 1.8946 | 1.8537 | 1.8256 | 1.7927 | 2.1748 | 1.8146 | 1.6828 | 1.5128 | 1.4239 | 1.7586 | 1.7375 |
| | 19:00 | 1.4276 | 1.4267 | 1.4234 | 1.4234 | 1.4526 | 1.4527 | 1.4527 | 1.3145 | 1.2933 | 1.3108 | 1.4427 | 1.4423 | 1.4426 | 1.4427 | 1.4418 | 1.4128 | 1.4129 | 1.4129 | 1.3529 | 1.2935 | 1.1366 | 0.9645 |
| Total | | 23.5518 | 20.186 | 18.2567 | 17.3813 | 16.2745 | 18.7113 | 18.5597 | 15.4486 | 15.1548 | 15.666 | 27.5294 | 23.8195 | 23.2219 | 22.37 | 21.0525 | 26.343 | 23.9463 | 22.812 | 21.7792 | 20.8416 | 21.3584 | 20.946 |
| Energy Saving % | | | 14.29% | 22.48% | 26.20% | 30.90% | 20.55% | 21.20% | 34.41% | 35.65% | 33.48% | | 13.48% | 15.65% | 18.74% | 23.53% | | 9.10% | 13.40% | 17.32% | 20.88% | | 1.93% |

### 5.4.1 South orientation simulations results

Compared with the base case scenario the chart in figure 5.4 shows that the case with louvers AR=3.0 (LW=3LS) with semitransparent material and VT 50% has the optimum energy reduction for south orientation among all the other scenarios during the 4 seasons with (35.13%), (19.06%), (42.80%) and (35.65%) energy saving on 21st of March, 20th of June, 20th of September and 15th of December, respectively.

- **Seasons and energy performance**

  The chart in figure 5.4 shows a significant variation in energy saving potential during the four seasons. The reasons for this variation in energy saving performance refer to the different in the sun azimuth angle and the amount of the direct solar radiation from season to season. The result shows that the energy saving reduction on June was lower compared to the other orientations. This could explained by the high sun azimuth angle during this month as illustrated in figure 5.5. This reduced the direct sun radiation on the South side which reduced the effect of the louvers shading. On contrast the optimum energy reduction with the whole louvers installations scenario was during September. Although the sun azimuth angle during December lower than September but the amount of direct solar radiation can reach 950 Lux (w/m2) in September and only 700 Lux (w/m2) during December as been shown in figure 4.27 and 4.30 in chapter 4. This explains the reason of the variation in energy saving reduction during the different seasons. Finally it must be noted that the cloudy sky condition during December could reduced the direct solar radiation.

Louvers AR=0.5 with (0°) louvers slate tilt angle has an (12.93%), (8.11%), (25.05%) and (14.29.48%) energy saving on 21st of March, 20th of June, 20th of September and 15th of December, respectively. Louvers AR=1 with (0°) louvers slate tilt angle has an (22.50%), (10.82%), (32.72%) and (22.48%) energy saving on 21st of March, 20th of June, 20th of September and 15th of December, respectively. Louvers ratio AR=2 with 0° louvers slate tilt angle has an (27.29%), (13.85%), (37.90%) and (26.20%) energy saving on 21st of March, 20th of June, 20th of September and 15th of December, respectively. Louvers ratio AR=3 with (0°) louvers slate tilt angle has an (31.33%), (15.82%), (39.26%) and (30.90%) energy saving on 21st of March, 20th of June, 20th of September and 15th of December, respectively.

louvers AR=3 and semitransparent material with 30% VT has an (33.95%), (18.61%), (40.75.27%) and (34.41%) energy saving on 21st of March, 20th of June, 20th of September and 15th of December, respectively. The case with VT 50% has an (35.13%), (19.06%), (42.80%) and (35.65%) energy saving on 21st of March, 20th of June, 20th of September and 15th of December, respectively. The case with VT 75% has an (32.70%), (18.80%), (40.13%) and (33.48%) energy saving on 21st of March, 20th of June, 20th of September and 15th of December, respectively.

The case with louvers AR=1 with 20° louvers slate tilt angle has an (24.76%), (12.31%), (35.27%) and (20.55%) energy saving on 21st of March, 20th of June, 20th of September and 15th of December, respectively. The case with louvers ratio AR=1 with 40° louvers slate tilt angle has an (21.30%), (10.45%), (28.20%) and (21.20%) energy saving on 21st of March, 20th of June, 20th of September and 15th of December, respectively.

In conclusions the south orientation results illustrate the main factors which have a significant effect in the louvers shading performance from season to season. The optimum energy saving reduction compared with the base case is the lovers AR=3 with semitransparent material VT=50.

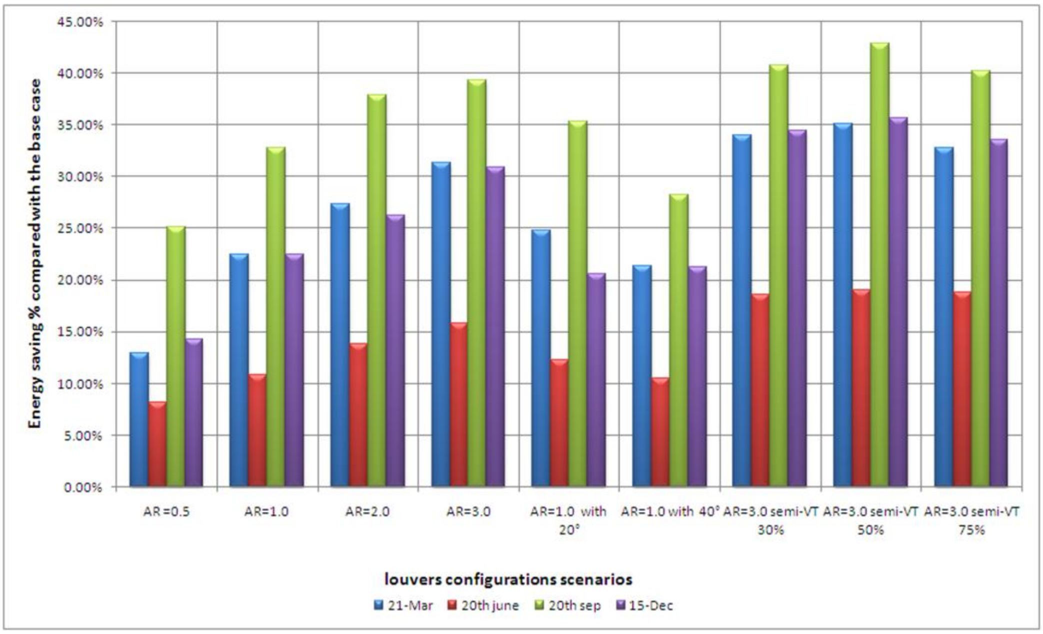



Figure 5.4. Energy saving reduction for louvers scenario compared with the base case for the South orientation.

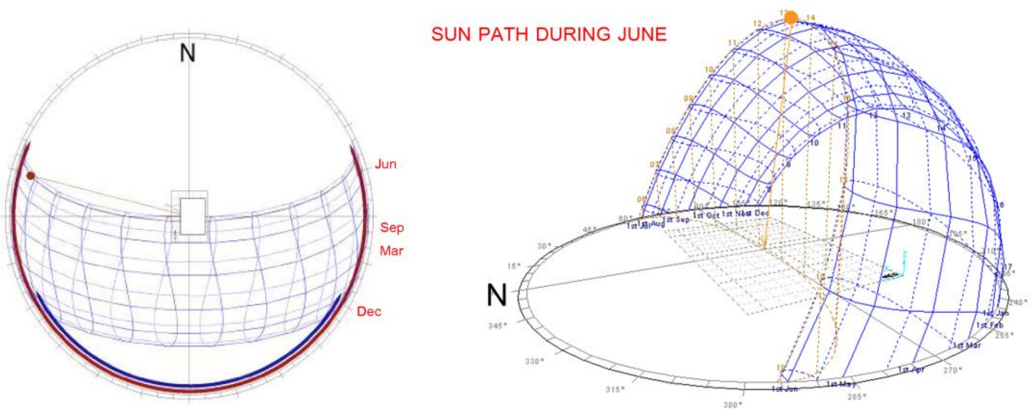



Figure 5.5. ECOTECT graph represent the sun path during the four selected seasons.

- **Annual Energy saving.**

The graph in Figure 5.6 shows a comparison between the average energy reductions for the South orientation during the four selected days compared with the base case scenario. The result shows that the optimum annual energy saving reduction was 33.16% for the louver AR=3 with semitransparent material and VT=50% compared with the base case. As the results the energy saving percentage is directly proportional with the AR value. The result shows that semitransparent louvers with VT value 50% are more efficient in energy saving than the VT value 75%. However the VT value with more than 50% increased the penetrated direct sun radiations which increase the energy consumptions. Finally the graph shows that the louvers with 20° slat tilt angle more efficient in energy saving than the lovers with 0° and 40° slat tilt angle for the south façade.

In summery it can be said that the optimum louvers design for the South orientation during the whole year seasons was with louvers AR=3 with semitransparent material with VT=50%. Moreover the changing in louvers ratio (LW) and (LS) is more efficient in energy saving than the changing in louvers angles.

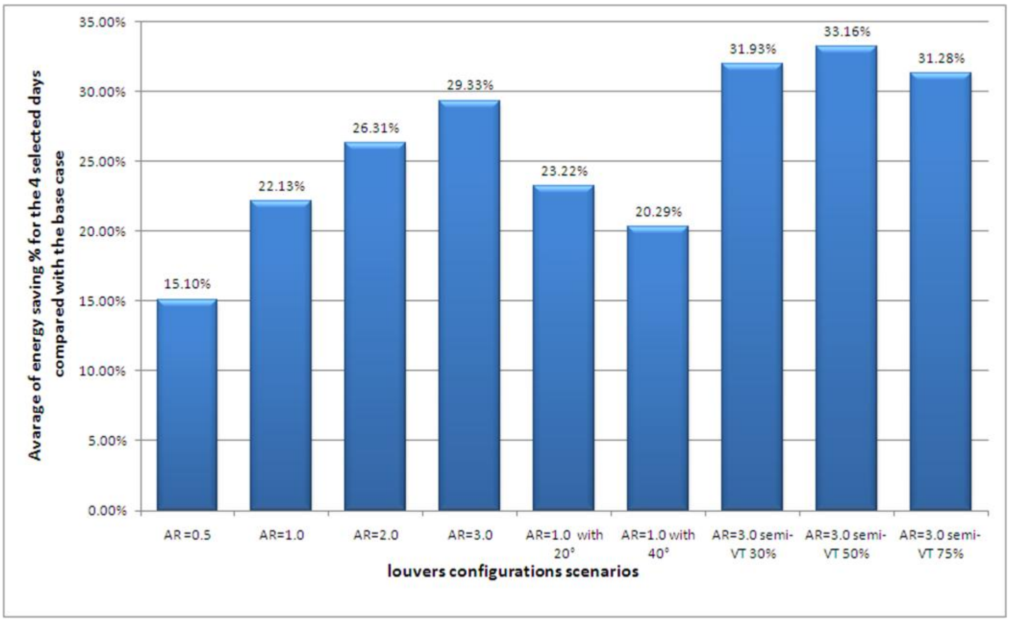



Figure 5.6. Average annual energy saving for louvers scenario compared with the base case for the South orientation.

### 5.4.2. East orientation simulations results

For the East orientation scenario the test was for the AR test group with 0° slat tilt angle. Compared with the base case scenario the case with louvers AR=3.0 has the optimum energy reduction among all the other scenarios during the 4 selected days with (27.23%), (26.12%), (23.36%) and (23.53%) energy saving on 21st of March, 20th of June, 20th of September and 15th of December, respectively. Louvers AR=0.5 has an (9.51%), (11.72%), (9.38%) and (13.48%) energy saving on 21st of March, 20th of June, 20th of September and 15th of December, respectively. Louvers ratio AR=1.0 has an (16.04%), (21.12%), (15.40%) and (15.65%) energy saving on 21st of March, 20th of June, 20th of September and 15th of December, respectively. Louvers AR=2.0 has an (17.48%), (23.00%), (17.81%) and (18.74%) energy saving on 21st of March, 20th of June, 20th of September and 15th of December, respectively. The charts in figure 5.7 illustrate Energy saving reduction for all louvers scenario compared with the base case.

- **Seasons and energy performance.**

The graph in figure 5.7 shows the percentage of energy saving reduction compared with the base case for different louvers ratio during the four seasons. In contrast of the south orientation results the chart shows slight different in energy saving performance during the four seasons. In general the chart shows that the lovers with AR=3.0 has the optimum results in energy saving during all the seasons. But also the graph shows a variation in the same louvers ratio performance from season to season. However for the louvers AR=3 was recorded the optimum energy reduction during March. On the other hand the louvers ratios AR=1.0 and AR=2.0 were recorded the optimum energy saving during June and the ratio AR=0.5 was recorded the optimum energy saving on December. This variation in same louvers ratio performance from season to season caused due the different in the sun path and the sun azimuth angle in different seasons.

In summery for the East orientation there are a slight variation in energy saving reduction during the four seasons due the slight different in sun path for the East orientation as seen in figure 5.5.

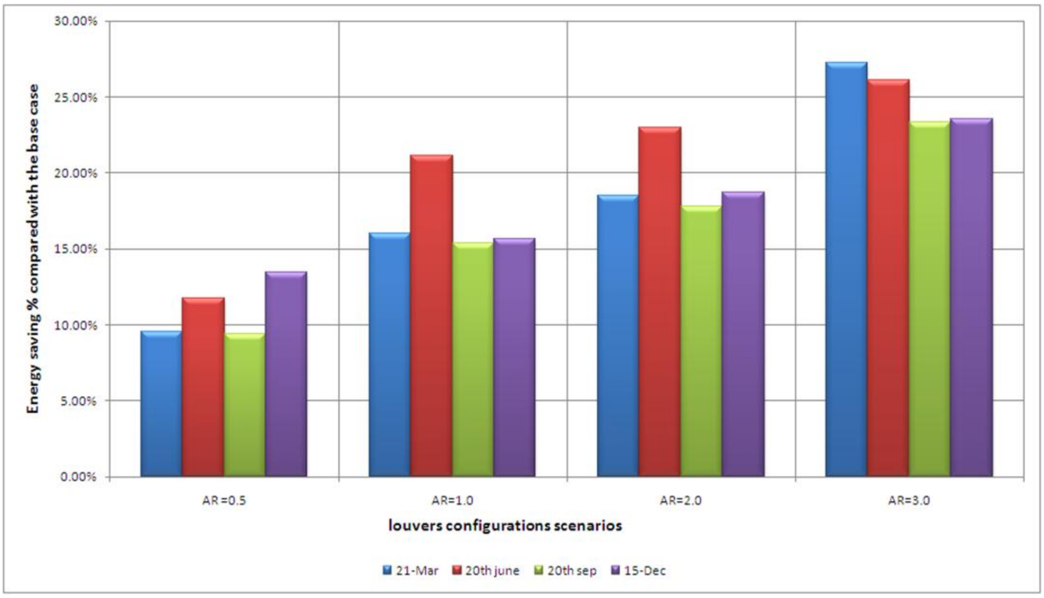



Figure 5.7. Energy saving reduction for louvers scenario compared with the base case for the East orientation.

- **Annual Energy saving.**

The graph in Figure 5.8 shows a comparison between the averages of the energy saving reduction for the East orientation during the four selected days compared with the base case scenario. The result shows that the optimum annual energy saving reduction was 25.06% for the louvers AR=3.0 compared with the base case. The second best scenario was for the louvers AR=2.0 with energy saving 19.51%.

In summery it can be said that the optimum louvers design for the East orientation during the whole year seasons was with louvers AR=3.0. Moreover the changing in louvers ratio (LW) and (LS) has a significant effect in terms of energy saving for the East orientation.

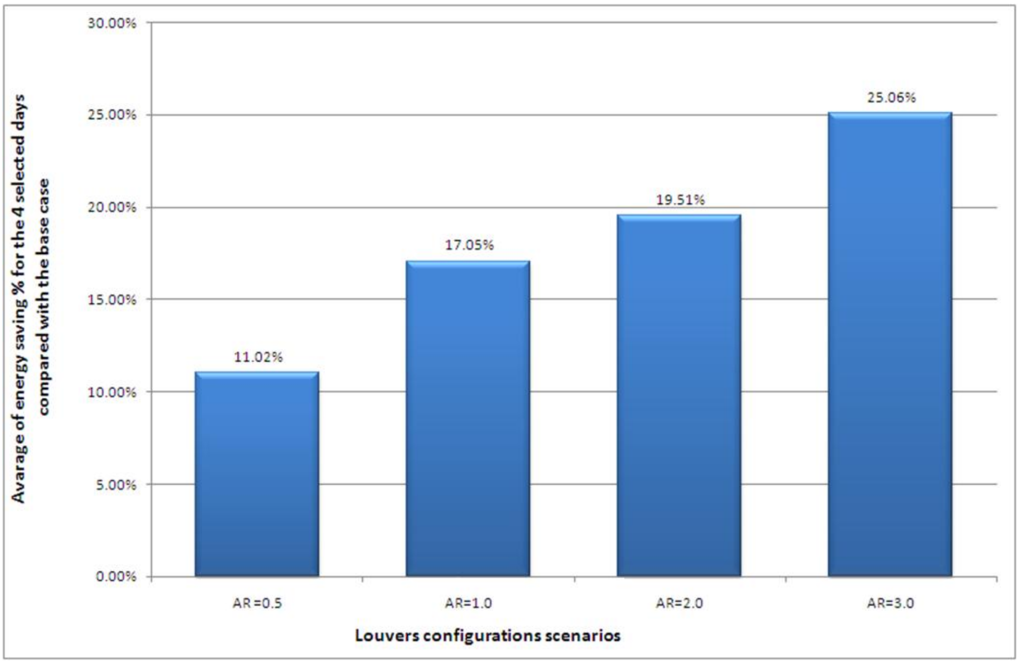



Figure 5.8. Average annual energy saving for louvers scenario compared with the base case for the East orientation.

### 5.4.3. West orientation simulations results

For the West orientation scenario the test was for the AR test group with 0° slat tilt angle. Compared with the base case scenario the case with louvers AR=3.0 has the optimum energy reduction among all the other scenarios during the four seasons with (24.64%), (23.57%), (24.80%) and (20.88%) energy saving on 21$^{st}$ of March, 20$^{th}$ of June, 20$^{th}$ of September and 15$^{th}$ of December, respectively. Louvers AR=0.5 has an (10.11%), (9.05 %), (10.32%) and (9.10%) energy saving on 21$^{st}$ of March, 20$^{th}$ of June, 20$^{th}$ of September and 15$^{th}$ of December, respectively. Louvers AR=1.0 has an (17.13%), (14.33%), (17.41%) and (13.40%) energy saving on 21$^{st}$ of March, 20$^{th}$ of June, 20$^{th}$ of September and 15$^{th}$ of December, respectively. Louvers AR=2.0 has an (19.92%), (18.03%), (21.17%) and (17.32%) energy saving on 21$^{st}$ of March, 20$^{th}$ of

June, 20th of September and 15th of December, respectively. The chart in figures 5.9 shows the Energy saving reduction for all louvers scenario compared with the base case.

- **Seasons and energy performance.**

The graph in figure 5.9 shows the percentage of energy saving reduction compared with the base case for different louvers ratio during the four seasons. In similar of the East orientation results the chart shows slight different in energy saving performance during the four seasons. The lovers with AR=3.0 has the optimum results in energy saving during all the seasons. The graph shows a small variation in the same louvers ratio performance from season to season. However all the louvers ratio scenario was recorded the highest energy reduction during March and September. In contrast of the East orientation the variations for the all louvers ratio were approximately recorded the same performance during all the seasons. These differences between the East and West orientation could be due the difference in the hourly heat gain for the whole building from morning to evening time.

In summery for the West orientation there are a slight variation in energy saving reduction during the four seasons due the slight difference in sun path for the west orientation as seen in figure 5.5. Also the difference in the louvers performance between the East and West orientation could be due the difference in the hourly heat gain for the whole building from morning to evening time. However for the east orientation the building released all the heat gain during the night time and starting to absorb heat from the morning sun. But for the West orientation scenario the building already spent around six hour of absorbing heat before facing the sun thus increase the energy used to cool the building.

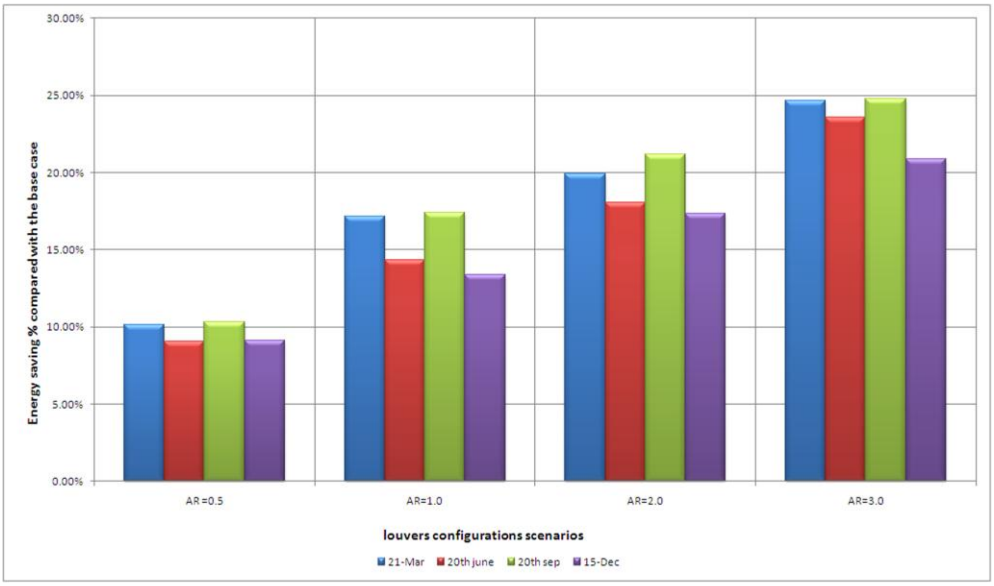


Figure 5.9. Energy saving reduction for louvers scenario compared with the base case for the West orientation.

- **Annual Energy saving.**

The graph in Figure 5.10 shows a comparison between the averages of the energy saving reduction for the West ordination during the four selected days compared with the base case scenario. The result shows that the optimum annual energy saving reduction was 23.43% for the louvers AR=3.0 compared with the base case. The second best scenario was for the louvers AR=2.5 with energy saving 19.11%.

In summery it can be said that the optimum louvers design for the East orientation during the whole year seasons was with louvers AR=3.0. Moreover the changing in louvers ratio (LW) and (LS) has a significant effect in terms of energy saving for the West orientation.

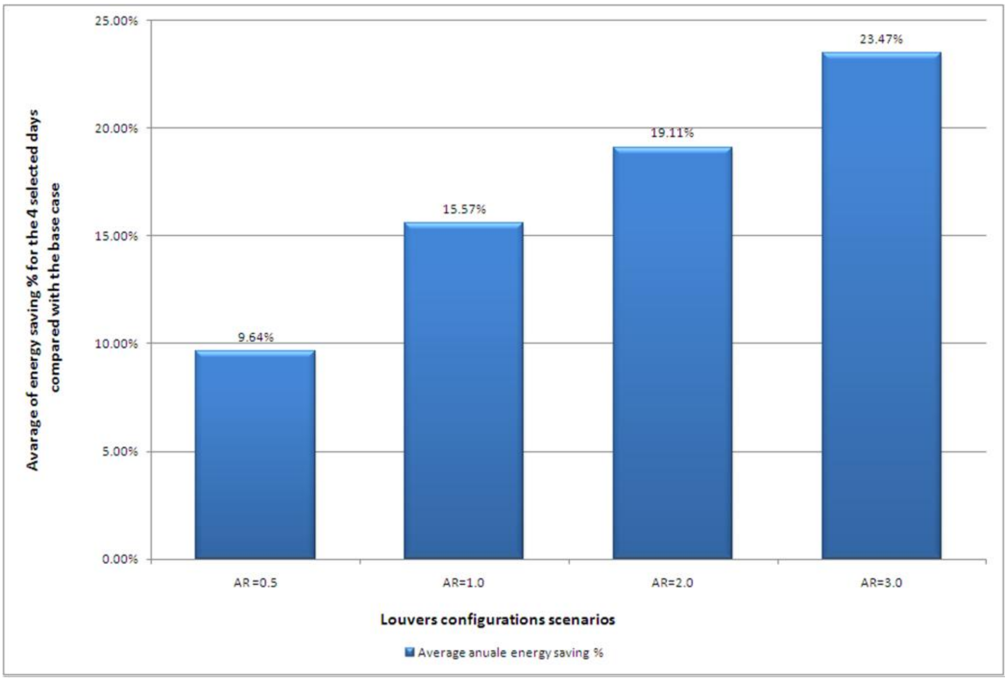



Figure 5.10. Average annual energy saving for louvers scenario compared with the base case for the West orientation.

## 5.5. Comparison between East, West and South orientations:

The effect of the different louvers configurations on the energy saving performance varies from South to East and West. Irrespective of the different louvers configuration and properties, the direct solar heat gain from the South orientation was generally greater than the input from the East and West orientations.

- **Seasons energy saving variations**

The results in figure 5.11 show the percentage of reduction in energy saving comparison with the base case (without louvers shading and light dimming system). The chart shows a very small energy saving for the North orientation compared with the other orientations. This huge difference cased due the sun path as been disused before. Also The chart shows that the percentage of the energy saving reduction for the South orientation was greater than the East and West orientations during March, September and December. During June the energy saving percentage for the South orientation was lower than the East and West due the high azimuth sun angle of this month which protects the south orientation from the direct solar radiation as been mentioned before.

The graph in Figure 5.12 illustrates the louvers energy saving percentage for the North, South, East and West during the four seasons. The graph shows a slight different in energy saving performance for the East and West during the four seasons. In contrast the graph shows a strong variation in energy saving percentage for the South orientation from season to season. This difference in energy saving for the South orientation could be due the difference in sun path, the amount of direct solar radiation and the weather in general from season to season. For the North orientation scenario the energy saving performance reaches the maximum during June, when the sun facing the North orientation only in this month during the whole year.

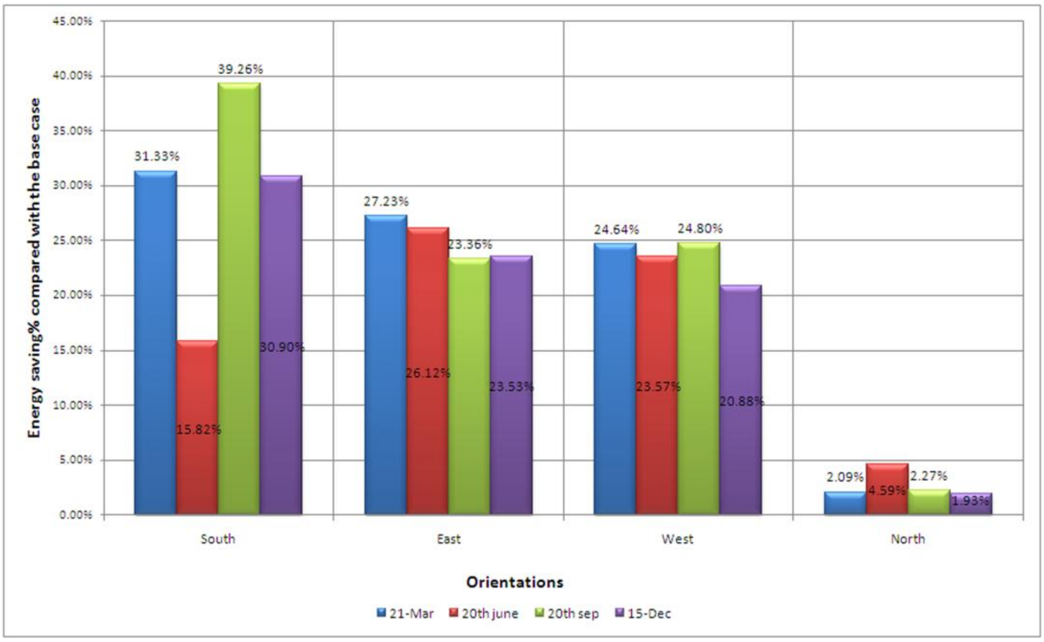



Figure 5.11. Energy saving% for louvers AR=3 compared with the base case for the West, East and South orientations during the four seasons.

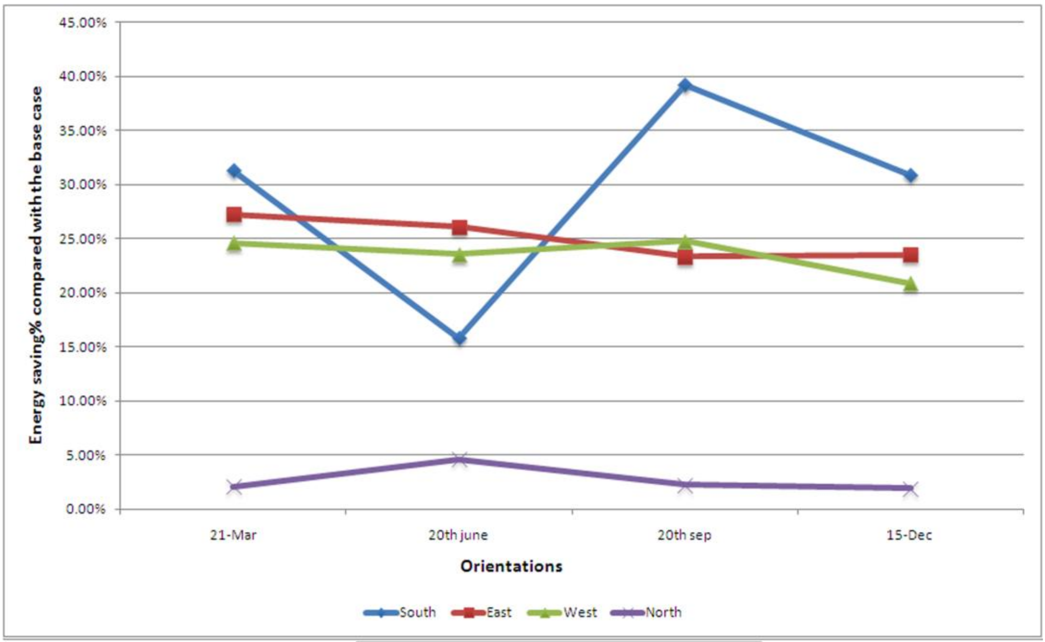



Figure 5.12. Energy saving% for louvers AR=3 compared with the base case for the West, East and South orientations during the four seasons.

- **Daytime energy saving variations**

The graph in figure 5.13 shows the hourly energy consumptions average over the four selected days for the South, East and west orientations. As the graph a sharp dropped in the hourly energy consumption was recorded for the East and West orientations. For the East orientation the energy consumptions generally was high from 7am to 12:30pm when the sun facing this orientation during this time as shown in figure 5.14. On contrast the west orientation facing the sun from 1pm to 6pm as shown in 5.15. On the other hand a slight deviation in energy consumption performance was recorded for the south orientation during the daytime. This approximate constant in energy consumption during the daytime caused due the sun facing the south orientation all the daytime.

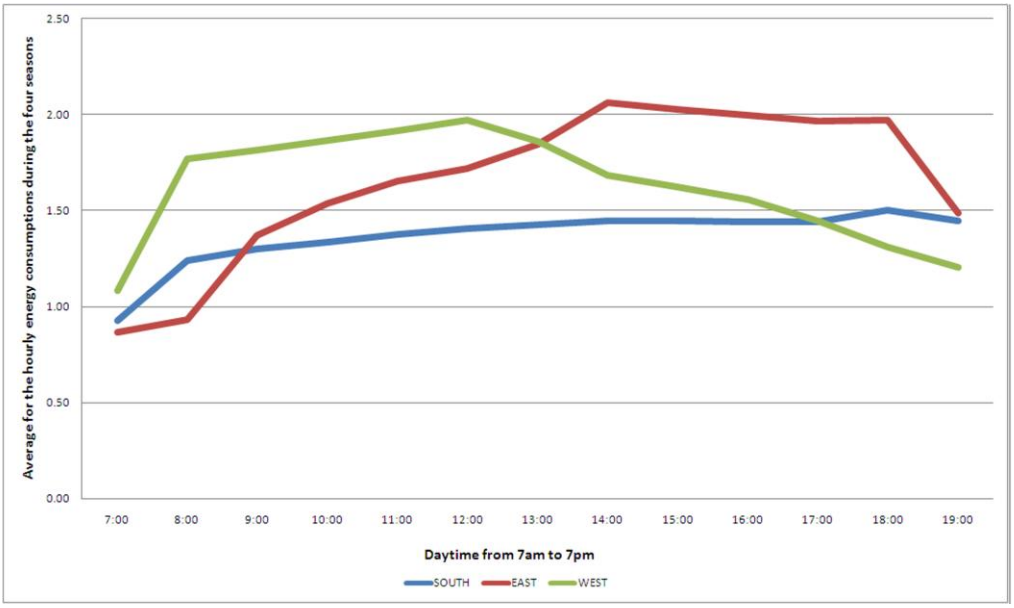



Figure 5.13. Hourly average energy consumptions for the louvers AR=3.0 during the four seasons for the South, East and west orientations.

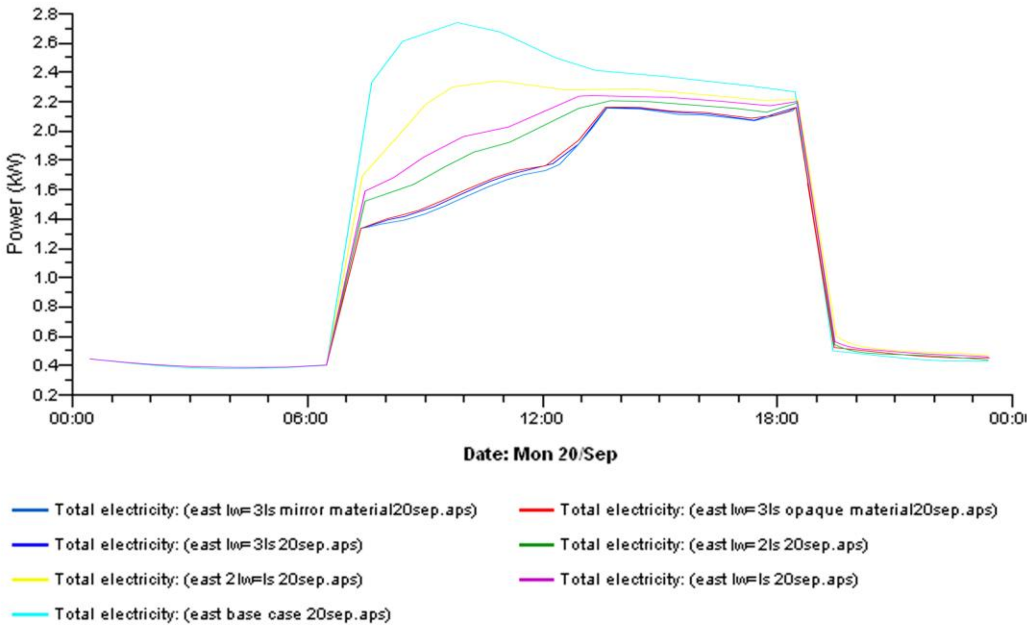



Figure 5.14. Hourly energy consumptions (KW) for all scenarios for the East orientation on 20th of Sep.

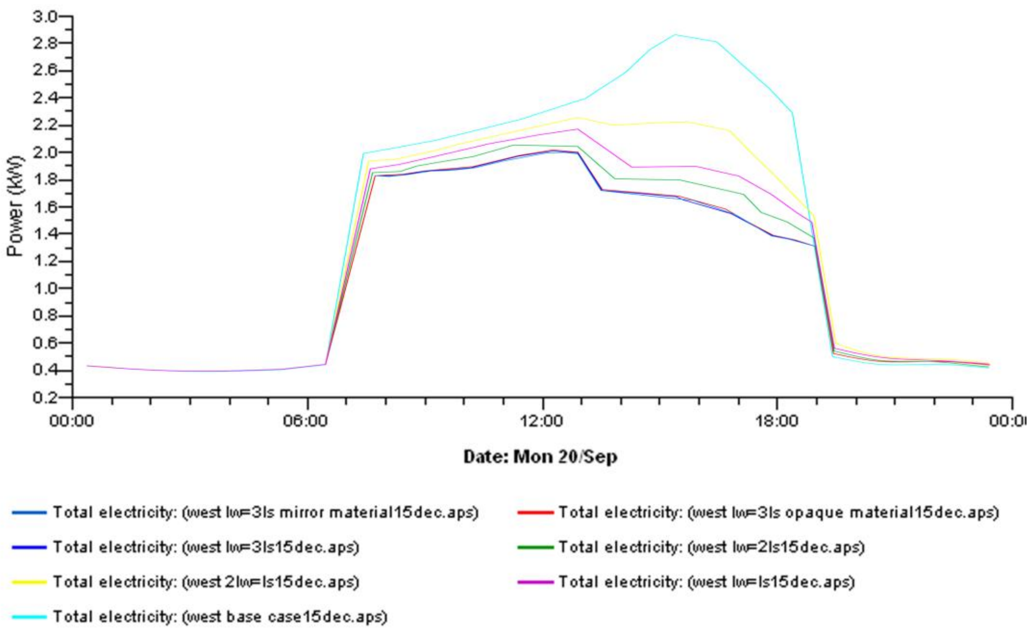



Figure 5.15. Hourly energy consumptions (KW) for all scenarios for the West orientation on 20th of Sep.

- **Annual Energy saving.**

The graph in figure 5.16 summarized the optimum annual energy saving reduction for the four orientations. The graph shows an annual energy reduction of 29.33% compared with the base case for the South orientation as a highest annual energy saving during the four seasons. The graph shows also a slight different in the annual energy saving for the East and West orientation with 25.06% annual energy saving for the East orientation and 23.47% for the West orientation. On contrast of all orientations scenario a minimal annual energy saving of 2.72% was recorded for the North orientation.

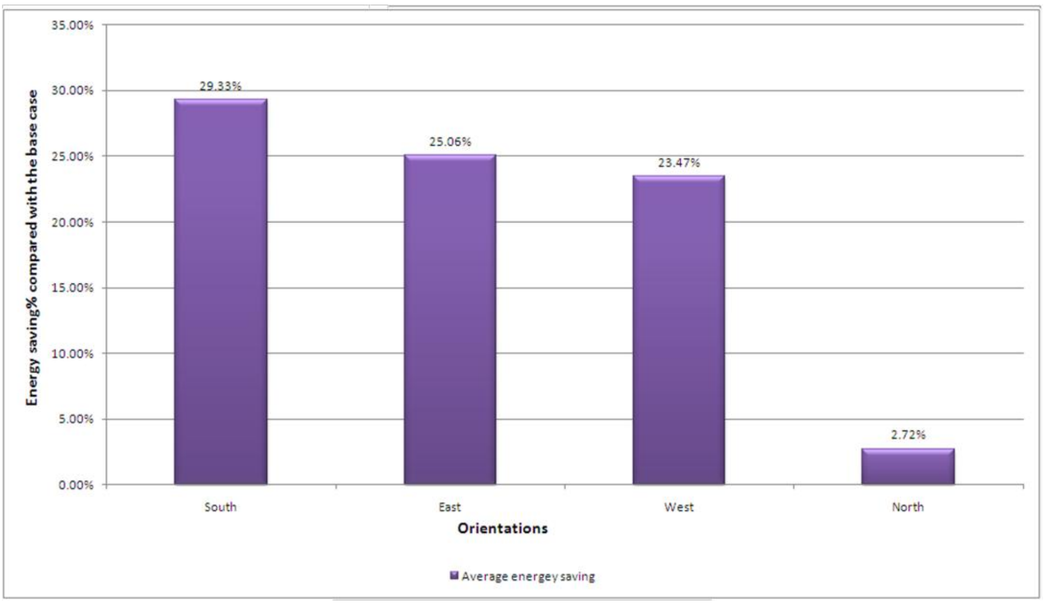



Figure 5.16. Average annual energy saving% for louvers AR=3.0 during the four selected days compared with the base case for the West, East and South orientations.

## 5.6. Comparison between the louvers configurations scenarios:

The effect of different louver shading configurations and properties was determined by comparing the total daily direct solar radiation input of each orientation. As results in figure 5.17 the percentage energy saving by each louvers configuration in comparison to without shading (the base case) various as the following:

- The effect of louvers AR.

  The results show a significant reduction in energy saving by changing the louvers width (LW) to the louver spacing distance (LS) ratio. The chart in Figure 5.17 shows that the AR=3.0 is the optimum louvers AR in comparison to base case in the all orientations during the whole year seasons with annual average energy saving 29.33%, 25.06% and 23.47% for the South, East and West orientations, respectively.

- The effect of Louvers color.

  The simulations test the effect of colors in lovers shading aimed to provide additional information on the contribution of reflected sun light in the interior illuminance. The effect of reflectivity created by this color could be compared and determined by the amount of transmitted reflected sun light. The results for the South, East and West orientations shows a very small reduction value of energy saving 0.353% to 0.415% compared with the standard martial color for louvers by changing the louvers color from opaque material to mirror material during the whole year seasons as shown in figure 5.17.

- Louvers with semitransparent materials.

  The simulations results shows an optimum reduction of 33.16% annual average energy saving by using louvers with semitransparent material with VT 50% for the optimum louvers AR=3 compared with the base case as been illustrated in figure 5.17. The simulation test illustrate that the VT value for the semitransparent material has the optimum energy saving in VT 50%. However this VT value allows penetrating the maximum defused sun light and at the same time protects the window from the direct sun radiation. The result shows also the VT 75% allow the direct sun radiation to penetrate inside the building which increase the cooling demand.

- Louvers slat tilt angles.

  The results show a reduction in energy saving by changing the louvers slat tilt angles. The chart in Figure 5.17 shows that the optimum louvers slat tilt angle is 20°. The annual average energy saving reduction Compared with the base case scenario was 22.13%, 23.22%, and 20.29% for 0°, 20° and 40°, respectively. It must be noted that the angle test was for the standard louvers AR=1.

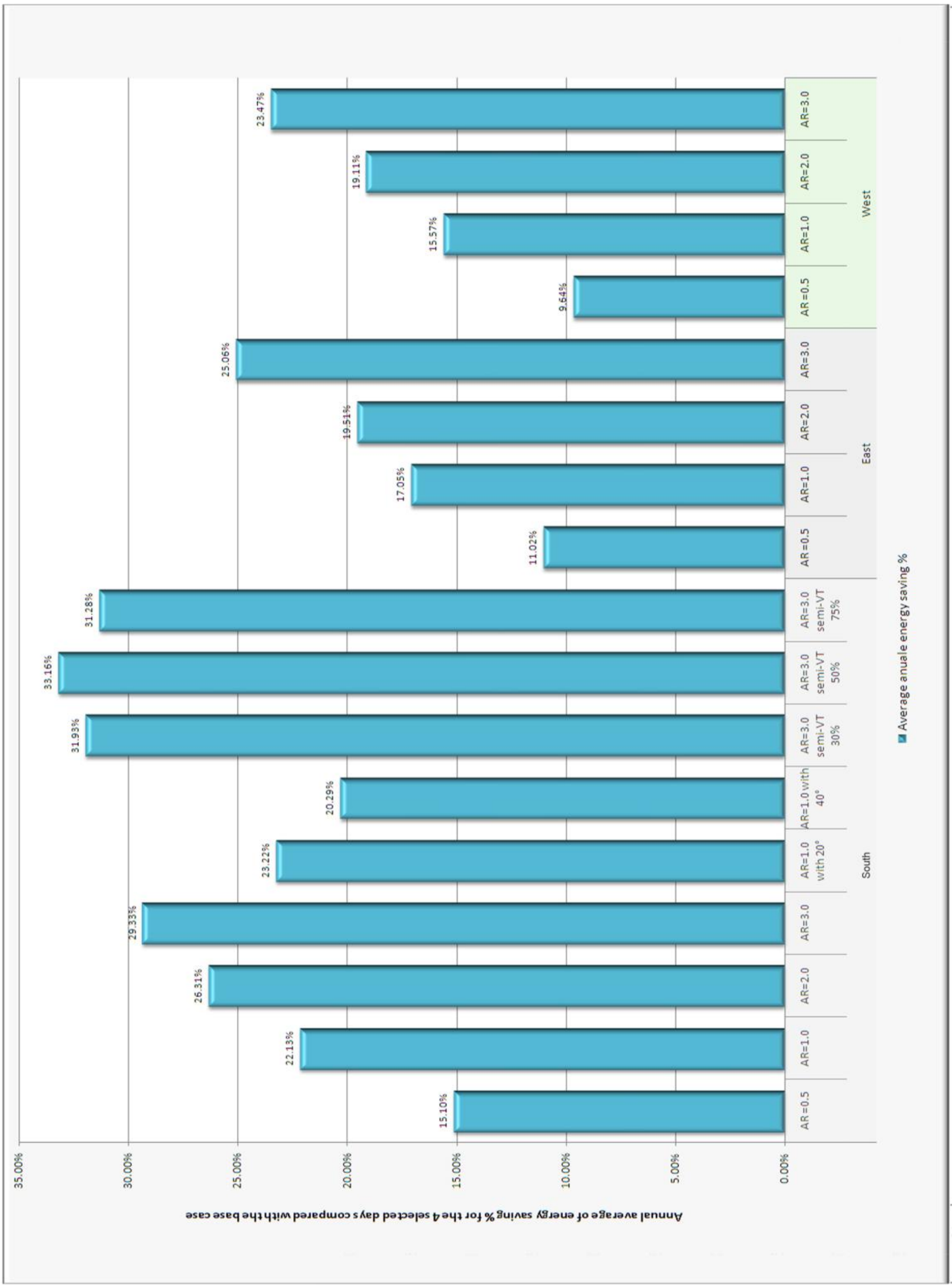



Figure 5.17. Average annual energy saving% for all louvers scenario compared with the base case for the West, East and South orientations.

# Chapter 6: Conclusions and Recommendations.

## 6.1. Conclusions

This thesis provide a design guidelines and recommendations for the external fixed shading devices configuration and properties in order to achieved the maximum energy saving potential during the four different seasons in UAE climate condition. The use of fixed external louvers in building façade with dimming light system achieved a significant reduction in energy saving with different scenario.

This study found that the louvers shade with the same ratio in (LW) and (LS) results approximately the same effect in energy saving. The optimum energy saving reduction was recorded by using lovers Aspect Ratio (AR=3.0) with semitransparent material with Visible Transmittance (VT) 50% was achieved 33.16% annual average energy saving comparison with the base case (without louvers shading and light dimming system) for the South orientation. The optimum louvers AR configuration was AR=3.0 with annual average percentage of reduction in energy saving 29.33%, 25.06% and 23.47% for the South, East and West orientations, respectively. The study found also that the changing in louvers AR, (LW) and (LS) is more efficient in energy saving than the changing in louvers angles.

The study illustrate that the VT value for the semitransparent material has the optimum energy saving in VT 50%. However this VT value allows penetrating the maximum defused sun light and protects the building facade from the direct sun radiation. The study shows also the semitransparent material with VT 75% allow the direct radiation to penetrate inside the building which increased the cooling load demand.

The energy saving reduction percentage for the South orientation is greater than the North, East and West due the larger amount of direct solar input from the south orientation than the other orientations. The study found that the annual energy reduction of 33.16% compared with the base case for the South orientation as a maximum annual energy saving during the four seasons. The study found also a slight difference in the annual energy saving for the East and West orientation with 25.06% annual energy saving for the East orientation and 23.47% for the West orientation.

The study for the South, East and West orientations shows a very small reduction value of energy saving 0.353% to 0.415% compared with the standard martial color for louvers by changing the louvers color from opaque material to mirror material during the whole year seasons.

This study illustrates the performance of louvers shading installation in energy saving from season to season and from time to time. For the South orientation the simulations found a significant energy saving on September, March and December with the whole louvers installations scenario, on the other hand a small energy saving reduction was recorded on June for the all louvers configurations due the high sun azimuth angle during this season.

For the East orientation a significant energy saving potential was recorded for all louvers configurations scenario during the four seasons from 07:00am to 12:30 pm, in contrast to 12:30pm to 06:00pm a lower energy saving performance was recorded. On the other hand the West orientation was recorded a significant energy saving potential for all louvers configurations scenario during the four seasons from 12:30pm to 06:30 pm, in contrast from 07:00am to 12:30pm a lower energy saving performance was recorded, These deferent in louvers performance cased due the deferent in hourly sun positions from East to West orientations.

## 6.2. Recommendations for future investigations

Throughout this investigation, different areas of study for the effect of louvers shading in buildings are illustrated for future work of investigation.

- The investigation on the performance of the louver color in the interior visual comfort and the illuminance uniformity. This factor is important especially for the commercial buildings in order to provide a healthy working environment.

- The effect of different louvers material with difference in thermal coefficient value and conductivity. However the material with high thermal coefficient value preferred in solar heating application to capture maximum sun radiation. This could increase the building skin temperatures which increase the cooling load demand as a consequence.

- The investigation on the effect of the louvers AR in the interior illuminance uniformity in order to avoid the glare effect.

- The effect of placing the louvers shading at a various locations from the window instead of cover the whole window area. Also the distance between the lovers plat and the building skin could reduce the façade temperature by the ventilation effect.

- Glass shading coefficient has an important role with the louvers configuration and properties. However the interaction between these parameters could result more energy saving.

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# Appendix A

## South Orientation Simulations

Table A.1. Excel sheet represent the hourly consumption energy measurements been collected for the South orientation during the four selected days.

| Date | Time | Energy Consumption For **South** Façade (KW) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Base Case | AR = 0.5 | AR = 1.0 | AR = 2.0 | AR = 3.0 | AR = 1.0 with 20° | AR = 1.0 with 40° | AR = 3.0 semi- VT 30% | AR = 3.0 semi- VT 50% | AR = 3.0 semi- VT 75% |
| 21st of March | 7:00 | 1.1567 | 1.0376 | 0.9121 | 0.9546 | 0.8935 | 0.9735 | 0.9987 | 0.9135 | 0.8847 | 0.8947 |
| | 8:00 | 1.6745 | 1.3154 | 1.1643 | 1.0945 | 1.0365 | 1.1267 | 1.1845 | 0.9926 | 0.9732 | 1.0237 |
| | 9:00 | 1.7798 | 1.4265 | 1.2343 | 1.1846 | 1.1145 | 1.1925 | 1.2645 | 1.0634 | 1.0543 | 1.0935 |
| | 10:00 | 1.8456 | 1.5212 | 1.3174 | 1.2574 | 1.1634 | 1.2835 | 1.3464 | 1.1398 | 1.0954 | 1.1316 |
| | 11:00 | 1.8867 | 1.61445 | 1.3834 | 1.2946 | 1.2213 | 1.3576 | 1.4213 | 1.1839 | 1.1703 | 1.2138 |
| | 12:00 | 1.9423 | 1.6823 | 1.4737 | 1.3487 | 1.2623 | 1.3835 | 1.4852 | 1.2265 | 1.1965 | 1.2645 |
| | 13:00 | 1.9712 | 1.7176 | 1.5267 | 1.3836 | 1.3114 | 1.4527 | 1.5593 | 1.2375 | 1.2265 | 1.2749 |
| | 14:00 | 2.0123 | 1.7523 | 1.5748 | 1.4325 | 1.3564 | 1.5143 | 1.5724 | 1.2436 | 1.2157 | 1.2701 |
| | 15:00 | 2.0243 | 1.7724 | 1.5823 | 1.4576 | 1.3618 | 1.5386 | 1.5746 | 1.2574 | 1.2345 | 1.265 |
| | 16:00 | 1.9934 | 1.7668 | 1.5579 | 1.4476 | 1.3517 | 1.5234 | 1.5784 | 1.2893 | 1.2567 | 1.3257 |
| | 17:00 | 1.9645 | 1.7323 | 1.5267 | 1.4427 | 1.3642 | 1.4853 | 1.5594 | 1.3275 | 1.3122 | 1.3759 |
| | 18:00 | 1.8723 | 1.6823 | 1.5123 | 1.4365 | 1.3725 | 1.4463 | 1.5256 | 1.3382 | 1.3205 | 1.3648 |
| | 19:00 | 1.4198 | 1.4787 | 1.4812 | 1.3834 | 1.3587 | 1.4365 | 1.4587 | 1.3378 | 1.3326 | 1.3466 |
| Total | | 23.5434 | 20.49985 | 18.2471 | 17.1183 | 16.1682 | 17.7144 | 18.529 | 15.551 | 15.2731 | 15.8448 |
| Energy saving % | | | 12.93% | 22.50% | 27.29% | 31.33% | 24.76% | 21.30% | 33.95% | 35.13% | 32.70% |
| 20th of June | 7:00 | 1.2176 | 1.0857 | 1.0856 | 1.0156 | 1.0528 | 0.9846 | 1.0548 | 0.9564 | 0.9414 | 0.9514 |
| | 8:00 | 2.0245 | 1.8256 | 1.7846 | 1.7365 | 1.6864 | 1.7846 | 1.7937 | 1.6722 | 1.6202 | 1.6602 |
| | 9:00 | 2.1156 | 1.8846 | 1.8456 | 1.7856 | 1.7537 | 1.8267 | 1.8456 | 1.7156 | 1.7126 | 1.7126 |
| | 10:00 | 2.1754 | 1.9635 | 1.8826 | 1.8354 | 1.7937 | 1.8426 | 1.9256 | 1.7426 | 1.7306 | 1.7306 |
| | 11:00 | 2.2435 | 2.0265 | 1.9735 | 1.8867 | 1.8536 | 1.9427 | 1.9725 | 1.7835 | 1.7725 | 1.7725 |
| | 12:00 | 2.2745 | 2.0715 | 2.0237 | 1.9324 | 1.8736 | 1.9836 | 2.0327 | 1.7925 | 1.7905 | 1.7905 |
| | 13:00 | 2.2835 | 2.0916 | 2.0376 | 1.9465 | 1.8735 | 1.9836 | 2.0267 | 1.8265 | 1.8245 | 1.8245 |
| | 14:00 | 2.2957 | 2.1183 | 2.0167 | 1.9576 | 1.8834 | 1.9826 | 2.0267 | 1.8167 | 1.8127 | 1.8127 |
| | 15:00 | 2.2786 | 2.0846 | 2.0176 | 1.9638 | 1.8956 | 1.9735 | 2.0156 | 1.7845 | 1.7815 | 1.7815 |
| | 16:00 | 2.2537 | 2.0715 | 1.9936 | 1.9364 | 1.8826 | 1.9634 | 2.0216 | 1.7936 | 1.7906 | 1.7906 |
| | 17:00 | 2.2235 | 2.0635 | 1.9845 | 1.9156 | 1.8645 | 1.9735 | 2.0245 | 1.8143 | 1.8113 | 1.8113 |
| | 18:00 | 2.1523 | 2.0635 | 1.9746 | 1.8905 | 1.8573 | 1.9746 | 1.9807 | 1.8225 | 1.8115 | 1.8215 |
| | 19:00 | 1.4123 | 1.4136 | 1.4154 | 1.4167 | 1.4156 | 1.4164 | 1.4127 | 1.4134 | 1.4134 | 1.4234 |
| Total | | 26.9507 | 24.764 | 24.0356 | 23.2193 | 22.6863 | 23.6324 | 24.1334 | 21.9343 | 21.8133 | 21.8833 |
| Energy Saving % | | | 8.11% | 10.82% | 13.85% | 15.82% | 12.31% | 10.45% | 18.61% | 19.06% | 18.80% |
| 20th of September | 7:00 | 1.1646 | 1.0537 | 1.0367 | 0.8526 | 0.8736 | 0.8635 | 0.8635 | 0.8636 | 0.8754 | 0.9349 |
| | 8:00 | 1.8967 | 1.3378 | 1.2725 | 1.2154 | 1.1836 | 1.2187 | 1.2856 | 1.1637 | 1.1329 | 1.1805 |
| | 9:00 | 1.9845 | 1.3827 | 1.2826 | 1.2315 | 1.1738 | 1.2524 | 2.3278 | 1.1626 | 1.1145 | 1.1709 |
| | 10:00 | 2.0856 | 1.4876 | 1.3327 | 1.2687 | 1.1937 | 1.2927 | 1.3625 | 1.1637 | 1.1285 | 1.1745 |
| | 11:00 | 2.1845 | 1.5872 | 1.3829 | 1.2716 | 1.1947 | 1.3414 | 1.4234 | 1.1738 | 1.1356 | 1.1938 |
| | 12:00 | 2.2716 | 1.6425 | 1.4325 | 1.2911 | 1.2287 | 1.3625 | 1.4628 | 1.1627 | 1.132 | 1.1761 |
| | 13:00 | 2.2916 | 1.6425 | 1.4527 | 1.2876 | 1.2026 | 1.3845 | 1.4875 | 1.1638 | 1.1248 | 1.1866 |
| | 14:00 | 2.2876 | 1.6112 | 1.44276 | 1.2765 | 1.2037 | 1.3825 | 1.4728 | 1.1738 | 1.1135 | 1.1704 |
| | 15:00 | 2.2463 | 1.5524 | 1.3965 | 1.2546 | 1.1826 | 1.3526 | 1.4527 | 1.1424 | 1.1242 | 1.1682 |
| | 16:00 | 2.1538 | 1.5517 | 1.3572 | 1.2254 | 1.1738 | 1.3165 | 1.3827 | 1.1711 | 1.1369 | 1.1741 |
| | 17:00 | 2.0527 | 1.5518 | 1.3276 | 1.2278 | 1.2036 | 1.2836 | 1.3527 | 1.1825 | 1.1461 | 1.1932 |
| | 18:00 | 1.9736 | 1.6618 | 1.3926 | 1.3571 | 1.4536 | 1.3926 | 1.4136 | 1.3956 | 1.2807 | 1.3593 |
| | 19:00 | 1.4526 | 1.4572 | 1.4145 | 1.4146 | 1.5527 | 1.4156 | 1.4134 | 1.5124 | 1.4525 | 1.5104 |
| Total | | 26.0457 | 19.5201 | 17.5238 | 16.1745 | 15.8207 | 16.8591 | 18.701 | 15.4317 | 14.8976 | 15.5929 |
| Enargy Saving % | | | 25.05% | 32.72% | 37.90% | 39.26% | 35.27% | 28.20% | 40.75% | 42.80% | 40.13% |
| 15th of December | 7:00 | 1.1736 | 0.8946 | 0.8926 | 0.8946 | 0.8937 | 1.9178 | 0.9537 | 0.9156 | 0.8802 | 0.8603 |
| | 8:00 | 1.6836 | 1.3387 | 1.1836 | 1.1964 | 1.0536 | 1.1536 | 1.1836 | 1.0178 | 0.9815 | 1.0634 |
| | 9:00 | 1.7836 | 1.4326 | 1.2436 | 1.2638 | 1.1537 | 1.2267 | 1.2752 | 1.0836 | 1.0804 | 1.1257 |
| | 10:00 | 1.8826 | 1.5248 | 1.3256 | 1.3145 | 1.1836 | 1.2894 | 1.3576 | 1.1367 | 1.0947 | 1.1565 |
| | 11:00 | 1.9227 | 1.5826 | 1.3927 | 1.3417 | 1.2278 | 1.3628 | 1.4226 | 1.1637 | 1.1537 | 1.1903 |
| | 12:00 | 1.9352 | 1.6537 | 1.4717 | 1.3527 | 1.2674 | 1.4326 | 1.4926 | 1.2365 | 1.1862 | 1.2657 |
| | 13:00 | 1.9826 | 1.6827 | 1.5354 | 1.3927 | 1.3243 | 1.4726 | 1.5726 | 1.2635 | 1.2379 | 1.2902 |
| | 14:00 | 2.0187 | 1.7245 | 1.5726 | 1.4378 | 1.3367 | 1.4927 | 1.5827 | 1.2715 | 1.2406 | 1.2835 |
| | 15:00 | 2.0367 | 1.7625 | 1.5839 | 1.4628 | 1.3527 | 1.4826 | 1.5946 | 1.2436 | 1.2347 | 1.2706 |
| | 16:00 | 1.9836 | 1.7536 | 1.571 | 1.4537 | 1.3527 | 1.4826 | 1.5824 | 1.2564 | 1.2548 | 1.2945 |
| | 17:00 | 1.8837 | 1.7254 | 1.5428 | 1.4236 | 1.3426 | 1.4726 | 1.5638 | 1.2736 | 1.2662 | 1.2807 |
| | 18:00 | 1.8376 | 1.6836 | 1.5178 | 1.4236 | 1.3331 | 1.4726 | 1.5256 | 1.2716 | 1.2506 | 1.2738 |
| | 19:00 | 1.4276 | 1.4267 | 1.4234 | 1.4234 | 1.4526 | 1.4527 | 1.4527 | 1.3145 | 1.2933 | 1.3108 |
| Total | | 23.5518 | 20.186 | 18.2567 | 17.3813 | 16.2745 | 18.7113 | 18.5597 | 15.4486 | 15.1548 | 15.666 |
| Energy Saving % | | | 14.29% | 22.48% | 26.20% | 30.90% | 20.55% | 21.20% | 34.41% | 35.65% | 33.48% |

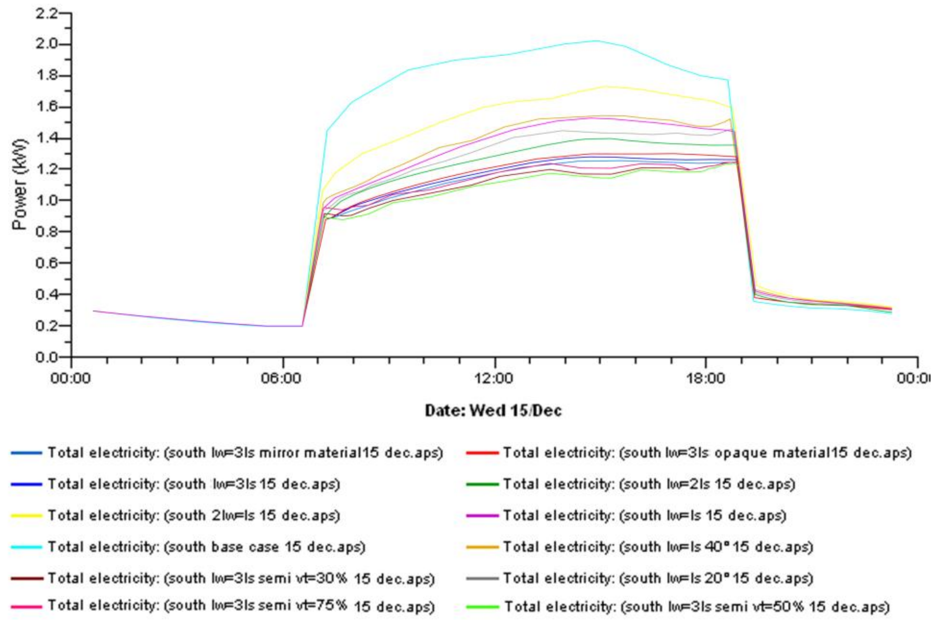


Figure A.1. Hourly energy consumptions (KW) for all scenarios for South orientation on 15th of Dec.

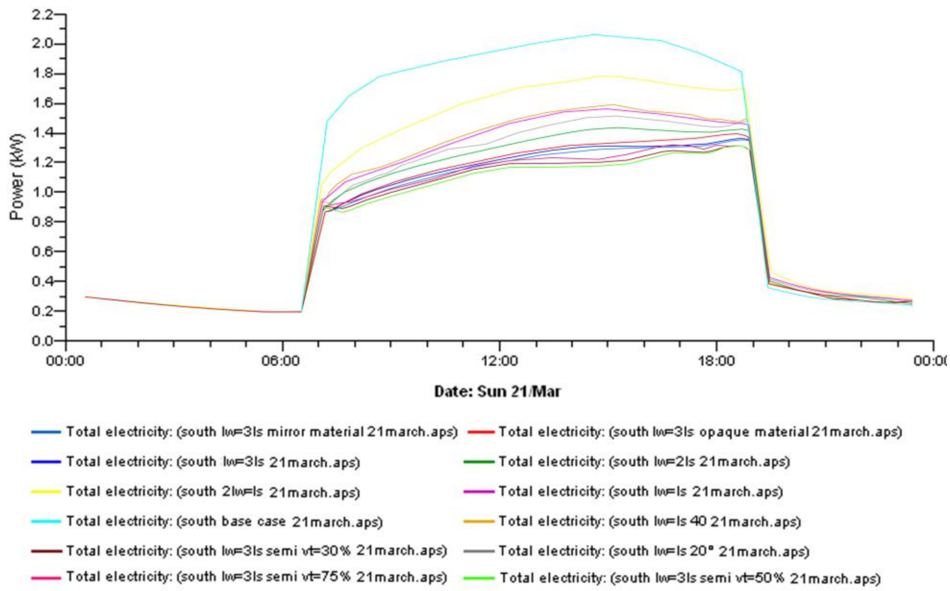


Figure A.2. Hourly energy consumptions (KW) for all scenarios the South orientation on 21st of March.

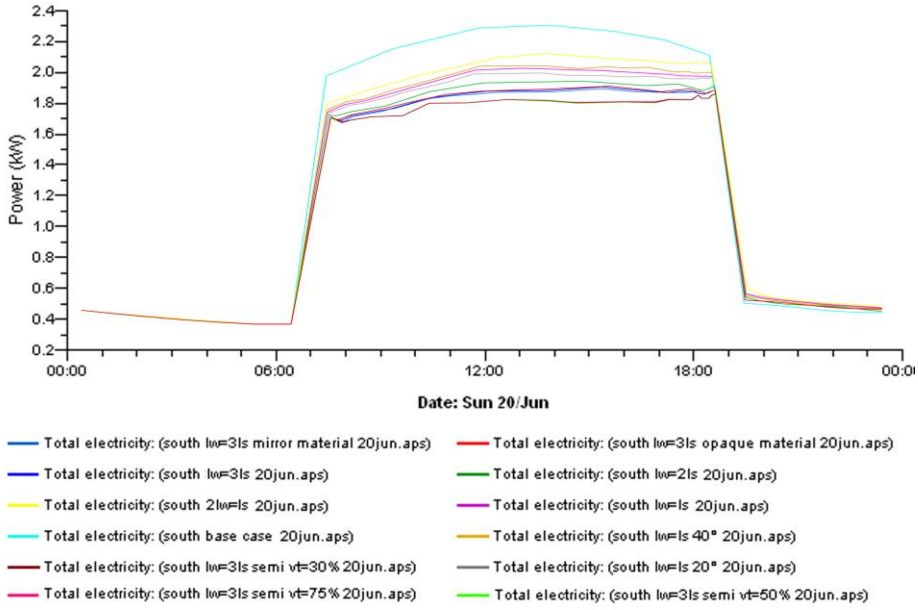


Figure A.3. Hourly energy consumptions (KW) for all scenarios for South orientation on 20th of Jun.

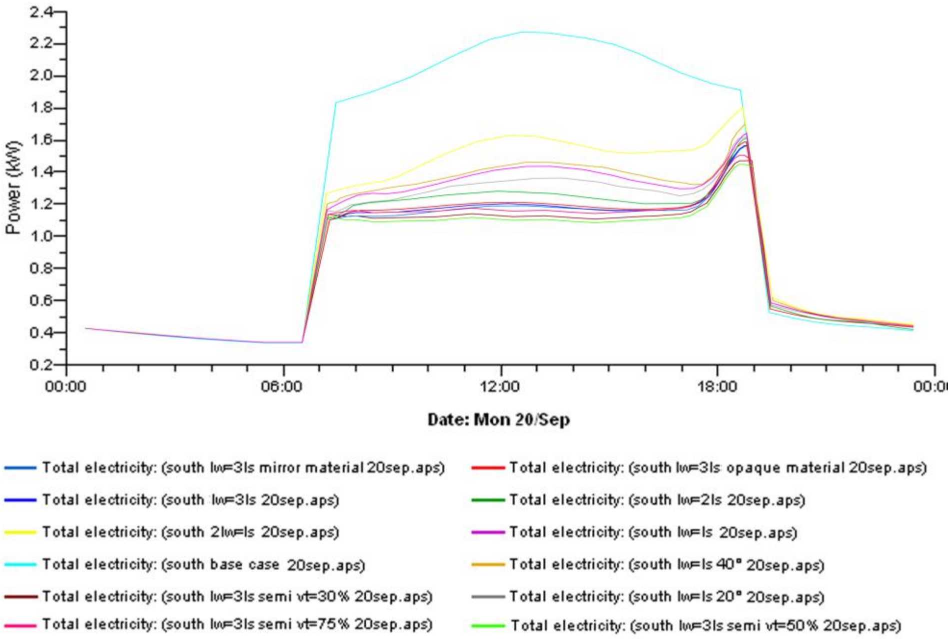


Figure A.4. Hourly energy consumptions (KW) for all scenarios for South orientation on 20th of Sep.

# Appendix B

East Orientation Simulations

Table B.1. Excel sheet represent the hourly consumption energy measurements been collected for the East orientation during the four selected days.

| Date | Time | Energy Consumption For **East** Façade (KW) | | | | |
|---|---|---|---|---|---|---|
| | | Base Case | AR = 0.5 | AR = 1.0 | AR = 2.0 | AR = 3.0 |
| 21st of March | 7:00 | 1.1524 | 1.0167 | 0.9156 | 0.9127 | 0.8156 |
| | 8:00 | 2.3167 | 1.5827 | 1.3846 | 1.2836 | 0.1235 |
| | 9:00 | 2.5314 | 2.0625 | 1.6537 | 1.5326 | 1.3265 |
| | 10:00 | 2.5715 | 2.1936 | 1.8726 | 1.7527 | 1.5134 |
| | 11:00 | 2.4725 | 2.2267 | 1.9537 | 1.8527 | 1.6325 |
| | 12:00 | 2.2917 | 2.1624 | 1.9534 | 1.8726 | 1.7156 |
| | 13:00 | 2.1935 | 2.0917 | 1.9927 | 1.9837 | 1.8524 |
| | 14:00 | 2.1762 | 2.0826 | 2.0325 | 2.0167 | 1.9827 |
| | 15:00 | 2.1536 | 2.0726 | 2.0236 | 1.9726 | 1.9276 |
| | 16:00 | 2.1176 | 2.0256 | 1.9827 | 1.9527 | 1.9134 |
| | 17:00 | 2.0725 | 1.9876 | 1.9726 | 1.9426 | 1.8836 |
| | 18:00 | 2.0256 | 1.9537 | 1.9236 | 1.9117 | 1.8928 |
| | 19:00 | 1.4526 | 1.4526 | 1.4524 | 1.4526 | 1.4527 |
| Total | | 27.5278 | 24.911 | 23.1137 | 22.4395 | 20.0323 |
| Energy saving % | | | 9.51% | 16.04% | 18.48% | 27.23% |
| 20th of June | 7:00 | 1.1726 | 1.0526 | 0.9856 | 0.9539 | 0.9256 |
| | 8:00 | 2.5326 | 1.7927 | 0.4937 | 1.2937 | 1.2167 |
| | 9:00 | 2.8436 | 2.1354 | 1.7326 | 1.5243 | 1.4256 |
| | 10:00 | 2.9167 | 2.2167 | 1.8837 | 1.6937 | 1.5825 |
| | 11:00 | 2.7415 | 2.2134 | 1.9367 | 1.7726 | 1.6536 |
| | 12:00 | 2.4928 | 2.2265 | 2.0267 | 1.7927 | 1.6927 |
| | 13:00 | 2.3917 | 2.3256 | 2.2967 | 1.9637 | 1.7435 |
| | 14:00 | 2.3728 | 2.2917 | 2.2567 | 2.1927 | 2.1563 |
| | 15:00 | 2.3562 | 2.2871 | 2.2145 | 2.1945 | 2.1325 |
| | 16:00 | 2.3526 | 2.2687 | 2.1963 | 2.1476 | 2.1153 |
| | 17:00 | 2.3573 | 2.2376 | 2.1927 | 2.1523 | 2.1163 |
| | 18:00 | 2.3365 | 2.2376 | 2.2176 | 2.1826 | 2.1536 |
| | 19:00 | 1.4937 | 1.5176 | 1.5145 | 1.5134 | 1.5154 |
| Total | | 30.3606 | 26.8032 | 23.948 | 23.3777 | 22.4296 |
| Energy Saving % | | | 11.72% | 21.12% | 23.00% | 26.12% |
| 20th of September | 7:00 | 1.2156 | 1.0376 | 0.9637 | 0.9423 | 0.9426 |
| | 8:00 | 2.3625 | 1.7927 | 1.6156 | 1.5234 | 1.3524 |
| | 9:00 | 2.5726 | 2.0927 | 1.7738 | 1.6354 | 1.4256 |
| | 10:00 | 2.6524 | 2.2376 | 1.8947 | 1.7725 | 1.5326 |
| | 11:00 | 2.5926 | 2.2716 | 1.9537 | 1.8635 | 1.6453 |
| | 12:00 | 2.4526 | 2.2343 | 2.0536 | 1.9725 | 1.6927 |
| | 13:00 | 2.3315 | 2.2234 | 2.1836 | 2.0936 | 1.8647 |
| | 14:00 | 2.3241 | 2.2165 | 2.1716 | 2.1427 | 2.0927 |
| | 15:00 | 2.3144 | 2.1936 | 2.1638 | 2.1426 | 2.0736 |
| | 16:00 | 2.2826 | 2.1873 | 2.1538 | 2.1156 | 2.0527 |
| | 17:00 | 2.2514 | 2.1735 | 2.1365 | 2.0938 | 2.0327 |
| | 18:00 | 2.2415 | 2.1543 | 2.1165 | 2.0836 | 2.0517 |
| | 19:00 | 1.4928 | 1.5426 | 1.4256 | 1.5248 | 1.5327 |
| Total | | 29.0866 | 26.3577 | 24.6065 | 23.9063 | 22.292 |
| Enargy Saving % | | | 9.38% | 15.40% | 17.81% | 23.36% |
| 15th of December | 7:00 | 1.1537 | 0.9927 | 0.8946 | 0.8847 | 0.7927 |
| | 8:00 | 2.2817 | 1.5245 | 1.2947 | 1.1938 | 1.0356 |
| | 9:00 | 2.4826 | 1.9354 | 1.6837 | 1.5137 | 1.3156 |
| | 10:00 | 2.4926 | 0.1345 | 1.9153 | 1.7346 | 1.5245 |
| | 11:00 | 2.4327 | 2.1937 | 1.9917 | 1.8436 | 1.6926 |
| | 12:00 | 2.3416 | 2.1847 | 1.9827 | 1.9123 | 1.7736 |
| | 13:00 | 2.2936 | 2.2123 | 2.0428 | 2.0123 | 1.9256 |
| | 14:00 | 2.2243 | 2.1735 | 2.1178 | 2.0938 | 2.0167 |
| | 15:00 | 2.1835 | 2.1142 | 2.0845 | 2.0217 | 1.9847 |
| | 16:00 | 2.1354 | 2.0346 | 1.9935 | 1.9736 | 1.9138 |
| | 17:00 | 2.0725 | 2.9825 | 1.9243 | 1.9176 | 1.8426 |
| | 18:00 | 1.9925 | 1.8946 | 1.8537 | 1.8256 | 1.7927 |
| | 19:00 | 1.4427 | 1.4423 | 1.4426 | 1.4427 | 1.4418 |
| Total | | 27.5294 | 23.8195 | 23.2219 | 22.37 | 21.0525 |
| Energy Saving % | | | 13.48% | 15.65% | 18.74% | 23.53% |

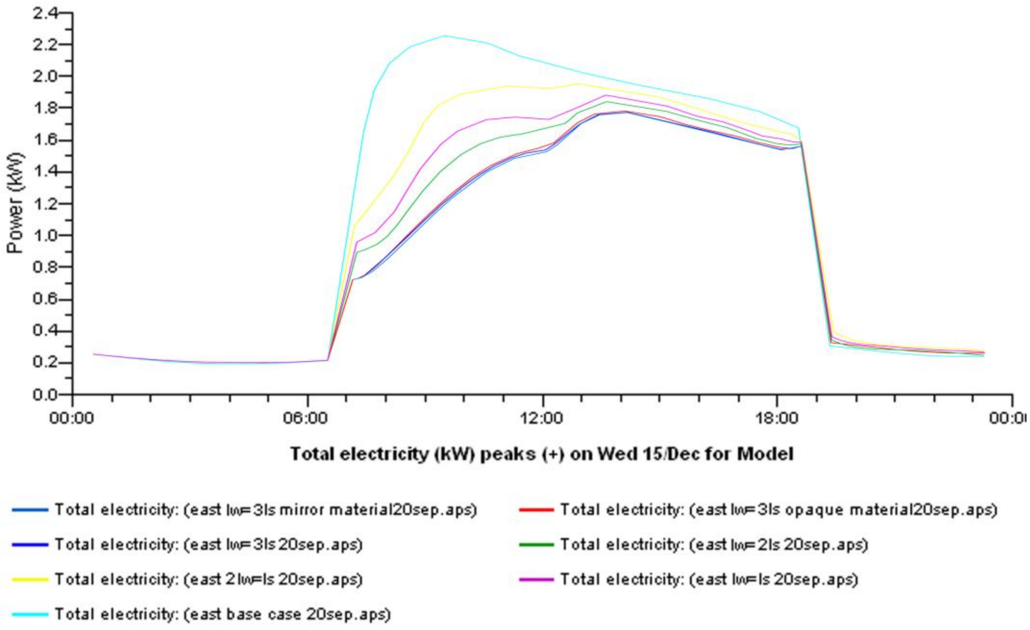


Figure B.1. Hourly energy consumptions (KW) for all scenarios for East orientation on 15th of Dec.

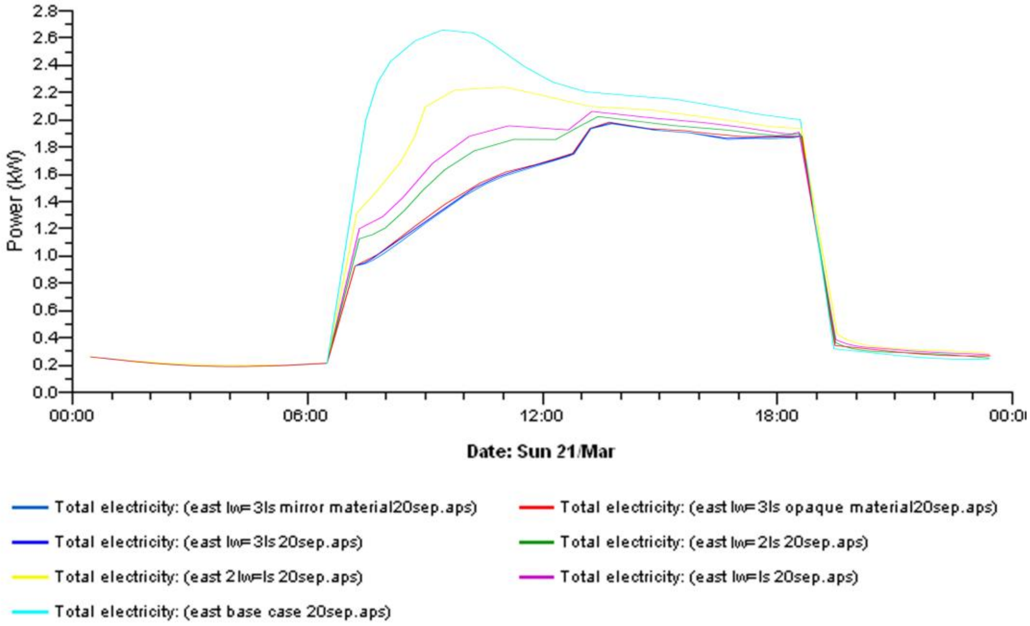


Figure B.2. Hourly energy consumptions (KW) for all scenarios for East orientation on 21st of March.

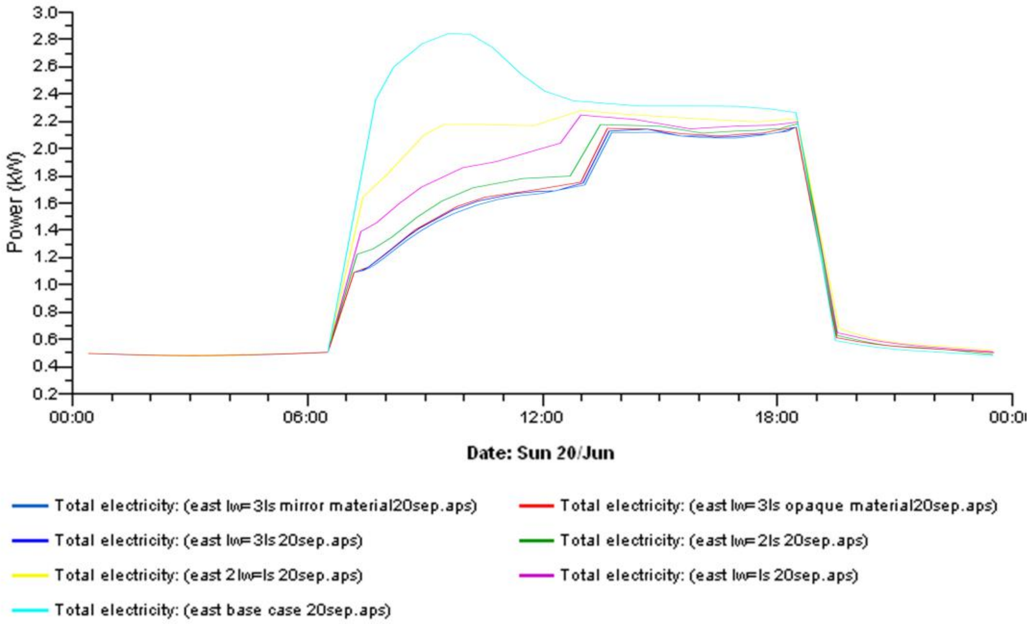


Figure B.3. Hourly energy consumptions (KW) for all scenarios for East orientation on 20th of Jun.

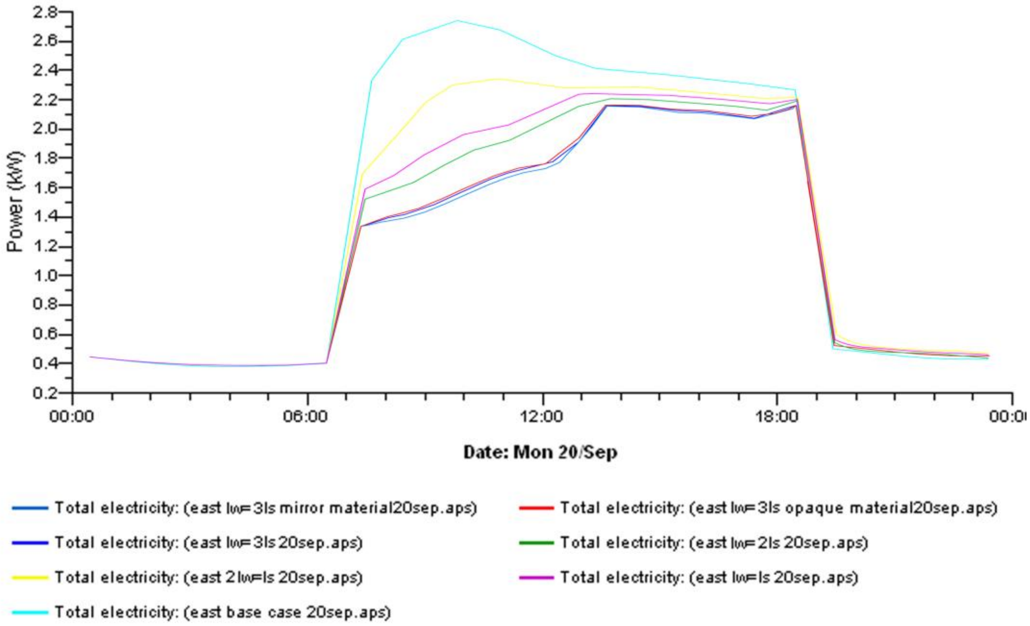


Figure B.4. Hourly energy consumptions (KW) for all scenarios for East orientation on 20th of Sep.

# Appendix C

West Orientation Simulations

Table C.1. Excel sheet represent the hourly consumption energy measurements been collected for the West orientation during the four selected days.

| Date | Time | Energy Consumption For **West** Façade (KW) | | | | |
|---|---|---|---|---|---|---|
| | | Base Case | AR = 0.5 | AR = 1.0 | AR = 2.0 | AR = 3.0 |
| 21st of March | 7:00 | 1.2316 | 1.2325 | 1.2323 | 1.2354 | 1.2341 |
| | 8:00 | 1.9846 | 1.9135 | 1.8635 | 1.8548 | 1.8524 |
| | 9:00 | 2.0126 | 1.9536 | 1.9156 | 1.8726 | 1.8425 |
| | 10:00 | 2.0836 | 1.9726 | 1.9465 | 1.8967 | 1.8736 |
| | 11:00 | 2.0927 | 2.0167 | 1.9726 | 1.9326 | 1.8825 |
| | 12:00 | 2.1236 | 2.0214 | 1.9827 | 1.9526 | 1.9223 |
| | 13:00 | 2.1537 | 2.0615 | 1.9736 | 1.8937 | 1.8256 |
| | 14:00 | 2.2436 | 2.1153 | 1.8936 | 1.8123 | 1.6537 |
| | 15:00 | 2.3927 | 2.1537 | 1.8736 | 1.7837 | 1.5938 |
| | 16:00 | 2.5473 | 2.1234 | 1.8167 | 1.6836 | 1.4738 |
| | 17:00 | 2.5145 | 2.0527 | 1.6127 | 1.5234 | 1.2871 |
| | 18:00 | 2.3176 | 1.5826 | 1.3526 | 1.2514 | 1.0927 |
| | 19:00 | 1.3547 | 1.1186 | 0.9827 | 0.9716 | 0.8526 |
| Total | | 27.0528 | 24.3181 | 22.4187 | 21.6644 | 20.3867 |
| Energy saving % | | | 10.11% | 17.13% | 19.92% | 24.64% |
| 20th of June | 7:00 | 1.1375 | 1.1527 | 1.1376 | 1.1325 | 1.1375 |
| | 8:00 | 2.0167 | 1.9167 | 1.8937 | 1.8726 | 1.8537 |
| | 9:00 | 2.0827 | 1.9726 | 1.9245 | 1.9167 | 1.8735 |
| | 10:00 | 2.1365 | 2.0178 | 1.9836 | 1.9526 | 1.8937 |
| | 11:00 | 2.2123 | 2.0837 | 2.0716 | 2.0256 | 1.9365 |
| | 12:00 | 2.2925 | 2.2278 | 2.1829 | 2.1378 | 2.0738 |
| | 13:00 | 2.4145 | 2.2545 | 2.2134 | 2.1536 | 1.6839 |
| | 14:00 | 2.5538 | 2.1919 | 1.9827 | 1.8356 | 1.6313 |
| | 15:00 | 2.7527 | 2.1837 | 1.9726 | 1.7839 | 1.5837 |
| | 16:00 | 2.7928 | 2.1738 | 1.8938 | 1.6838 | 1.5132 |
| | 17:00 | 2.6728 | 2.0537 | 1.6927 | 1.5526 | 1.4256 |
| | 18:00 | 2.4387 | 1.7529 | 1.5837 | 1.4537 | 1.3527 |
| | 19:00 | 0.3527 | 1.3526 | 1.3312 | 1.3327 | 1.3326 |
| Total | | 27.8562 | 25.3344 | 23.864 | 22.8337 | 21.2917 |
| Energy Saving % | | | 9.05% | 14.33% | 18.03% | 23.57% |
| 20th of September | 7:00 | 1.1635 | 1.228 | 1.0118 | 1.0129 | 1.0167 |
| | 8:00 | 2.0327 | 1.9539 | 1.9138 | 1.8739 | 1.8326 |
| | 9:00 | 2.0828 | 1.9938 | 1.9736 | 1.9128 | 1.8645 |
| | 10:00 | 2.1628 | 2.0839 | 2.0249 | 1.9839 | 1.8826 |
| | 11:00 | 2.2237 | 2.1317 | 2.0829 | 2.0529 | 1.9524 |
| | 12:00 | 2.2917 | 2.2116 | 2.1418 | 2.0643 | 1.9927 |
| | 13:00 | 2.3849 | 2.2739 | 2.1829 | 2.0534 | 2.0166 |
| | 14:00 | 2.6628 | 2.2239 | 1.9829 | 1.8256 | 1.7356 |
| | 15:00 | 2.7228 | 2.2429 | 1.8929 | 1.8156 | 1.6927 |
| | 16:00 | 2.8537 | 2.2349 | 1.8949 | 1.7726 | 1.6528 |
| | 17:00 | 2.7129 | 2.1346 | 1.8329 | 1.7234 | 1.5534 |
| | 18:00 | 2.4248 | 1.8518 | 1.6939 | 1.5234 | 1.3827 |
| | 19:00 | 1.4147 | 1.5627 | 1.4328 | 1.3526 | 1.3328 |
| Total | | 29.1338 | 26.1276 | 24.062 | 22.9673 | 21.9081 |
| Enargy Saving % | | | 10.32% | 17.41% | 21.17% | 24.80% |
| 15th of December | 7:00 | 1.1529 | 1.0329 | 1.0238 | 0.9529 | 0.9528 |
| | 8:00 | 1.7228 | 1.6329 | 1.5928 | 1.5729 | 1.5328 |
| | 9:00 | 1.8728 | 1.7939 | 1.7639 | 1.6929 | 1.6728 |
| | 10:00 | 1.9828 | 1.9239 | 1.8929 | 1.8339 | 1.8128 |
| | 11:00 | 2.0328 | 1.9639 | 1.9328 | 1.8939 | 1.8928 |
| | 12:00 | 2.0929 | 2.0129 | 1.9428 | 1.9128 | 1.8928 |
| | 13:00 | 2.2229 | 2.1729 | 2.0549 | 1.9828 | 1.9129 |
| | 14:00 | 2.5338 | 2.0739 | 1.9239 | 1.8528 | 1.7129 |
| | 15:00 | 2.4239 | 2.0839 | 1.8939 | 1.7838 | 1.6338 |
| | 16:00 | 2.3829 | 2.0739 | 1.8828 | 1.7629 | 1.5839 |
| | 17:00 | 2.3349 | 1.9538 | 1.8118 | 1.6719 | 1.5239 |
| | 18:00 | 2.1748 | 1.8146 | 1.6828 | 1.5128 | 1.4239 |
| | 19:00 | 1.4128 | 1.4129 | 1.4129 | 1.3529 | 1.2935 |
| Total | | 26.343 | 23.9463 | 22.812 | 21.7792 | 20.8416 |
| Energy Saving % | | | 9.10% | 13.40% | 17.32% | 20.88% |

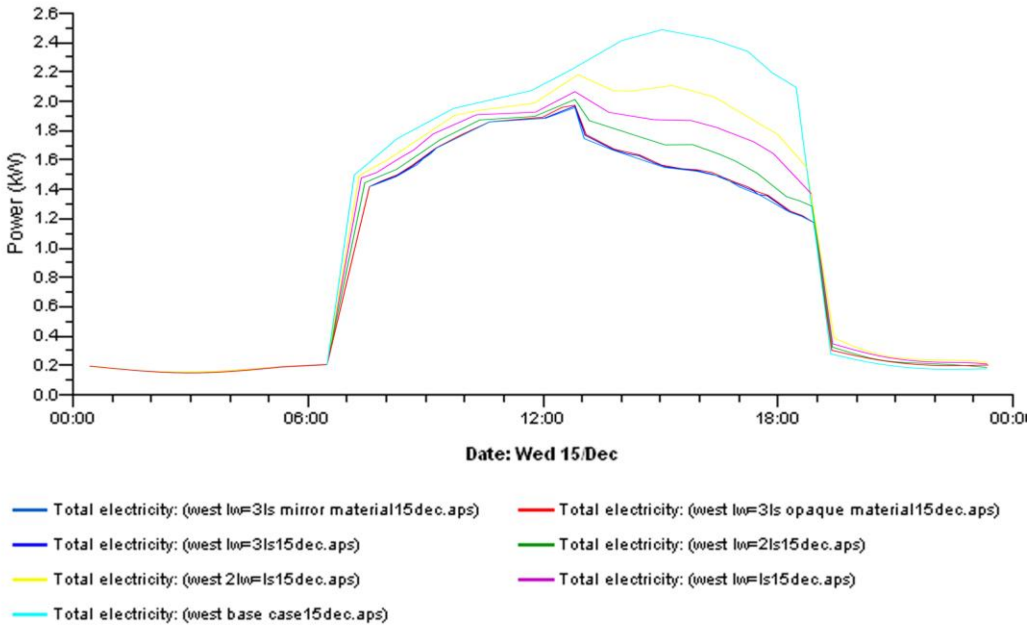


Figure C.1. Hourly energy consumptions (KW) for all scenarios for West orientation on 15th of Dec.

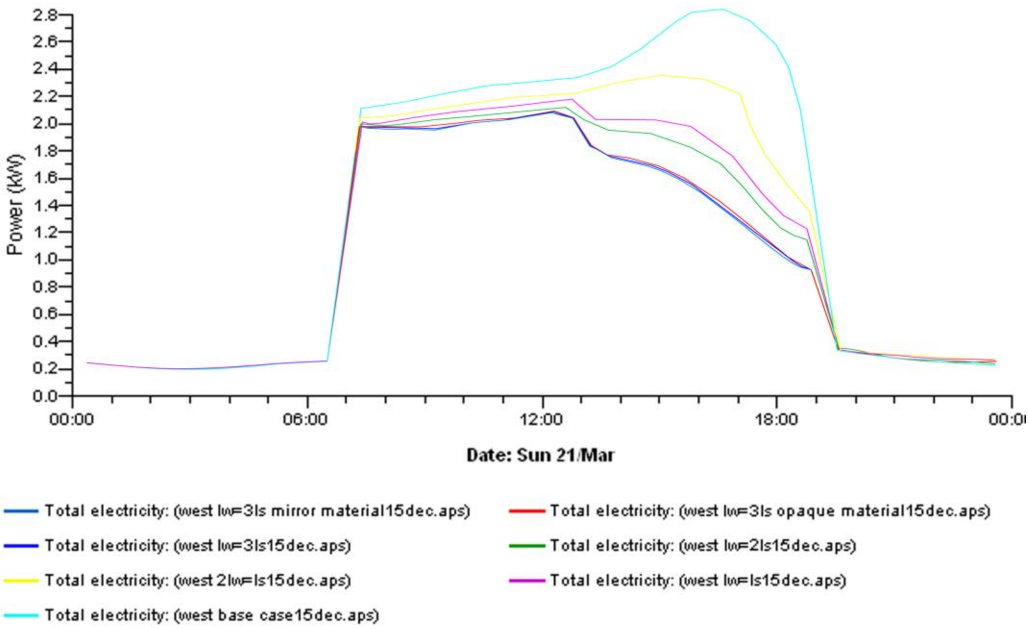


Figure C.2. Hourly energy consumptions (KW) for all scenarios for West orientation on 21st of March.

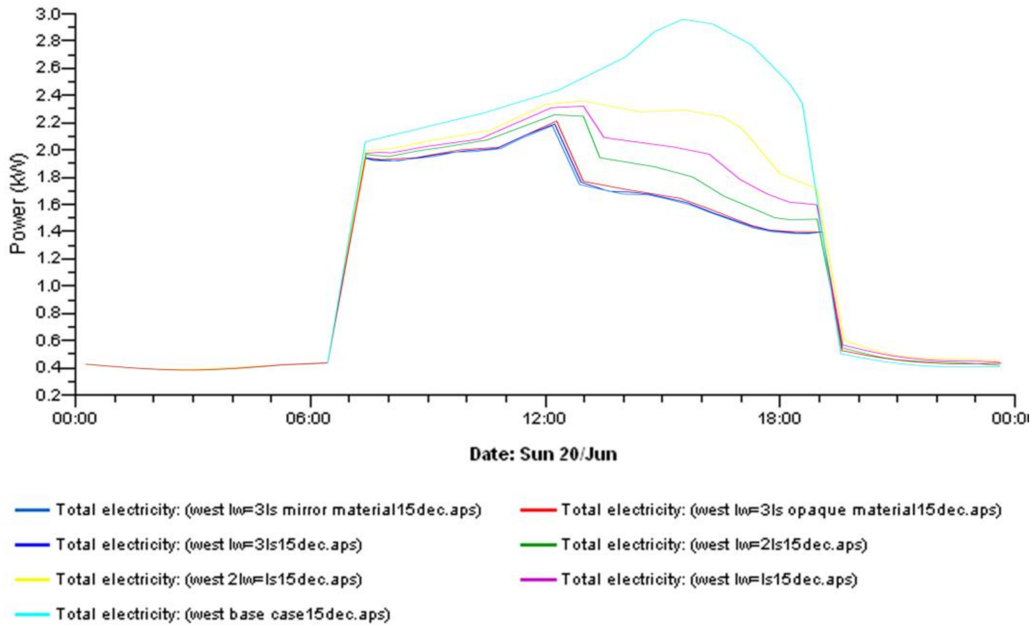


Figure C.3. Hourly energy consumptions (KW) for all scenarios for West orientation on 20th of Jun.

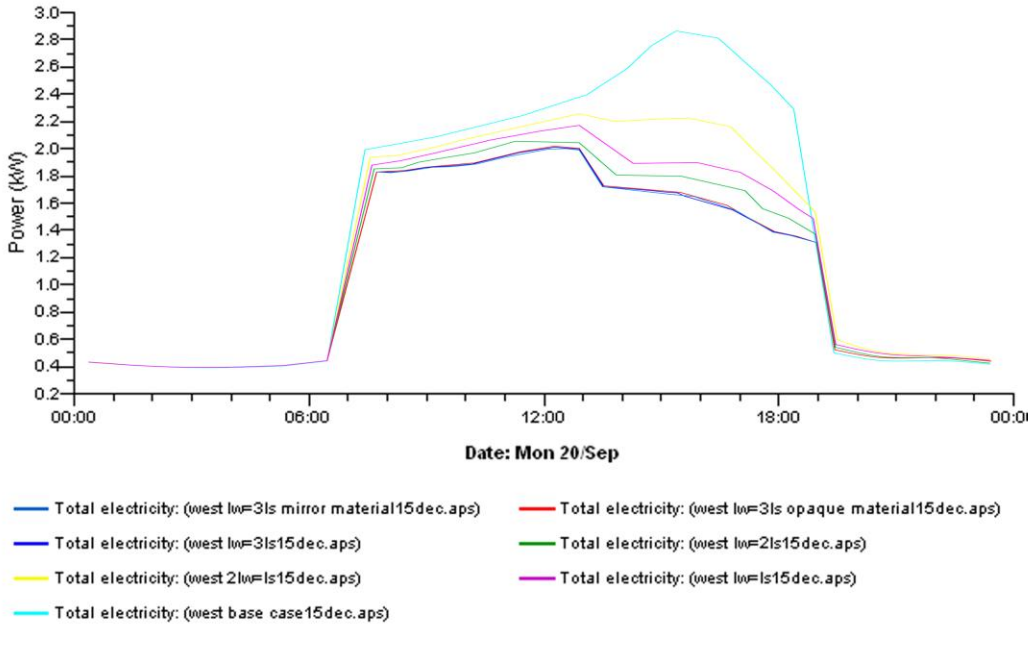


Figure C.4. Hourly energy consumptions (KW) for all scenarios for West orientation on 20th of Sep.

# Appendix D

North Orientation Simulations

Table D.1. Excel sheet represent the hourly consumption energy measurements been collected for the North orientation during March and June.

| Date | Time | Energy Con- For **North** Façade (KW) | |
|---|---|---|---|
| | | Base Case | AR = 3.0 |
| 21st of March | 7:00 | 1.0356 | 1.1106 |
| | 8:00 | 1.7151 | 1.6625 |
| | 9:00 | 1.8547 | 1.8247 |
| | 10:00 | 1.9621 | 1.9289 |
| | 11:00 | 2.0348 | 2.0201 |
| | 12:00 | 2.0739 | 2.0425 |
| | 13:00 | 2.0876 | 2.0534 |
| | 14:00 | 2.0905 | 2.0852 |
| | 15:00 | 2.1237 | 2.1027 |
| | 16:00 | 2.0958 | 2.0673 |
| | 17:00 | 2.0645 | 2.0356 |
| | 18:00 | 2.0136 | 1.9642 |
| | 19:00 | 1.2769 | 1.0205 |
| Total | | 24.4288 | 23.9182 |
| Energy saving % | | | 2.09% |
| 20th of June | 7:00 | 1.2704 | 1.0863 |
| | 8:00 | 2.1453 | 2.0271 |
| | 9:00 | 2.1942 | 2.0561 |
| | 10:00 | 2.2356 | 2.0964 |
| | 11:00 | 2.2507 | 2.1806 |
| | 12:00 | 2.2638 | 2.1925 |
| | 13:00 | 2.2815 | 2.2206 |
| | 14:00 | 2.2768 | 2.2304 |
| | 15:00 | 2.3204 | 2.2795 |
| | 16:00 | 2.3547 | 2.2637 |
| | 17:00 | 2.3671 | 2.2149 |
| | 18:00 | 2.3105 | 2.1506 |
| | 19:00 | 1.4658 | 1.4652 |
| Total | | 27.7368 | 26.4639 |
| Energy Saving % | | | 4.59% |

Table D.2. Excel sheet represent the hourly consumption energy measurements been collected for the North orientation during September and December.

| Date | Time | Energy Con- For **North** Façade (KW) | |
|---|---|---|---|
| | | Base Case | AR = 3.0 |
| 20th of September | 7:00 | 1.1736 | 1.0163 |
| | 8:00 | 2.0149 | 1.9753 |
| | 9:00 | 2.0834 | 2.0548 |
| | 10:00 | 2.1748 | 2.1358 |
| | 11:00 | 2.1959 | 2.1776 |
| | 12:00 | 2.2504 | 2.2254 |
| | 13:00 | 2.2615 | 2.2349 |
| | 14:00 | 2.2583 | 2.2307 |
| | 15:00 | 2.2427 | 2.2178 |
| | 16:00 | 2.2261 | 2.1956 |
| | 17:00 | 2.1973 | 2.1746 |
| | 18:00 | 2.1748 | 2.1547 |
| | 19:00 | 1.4346 | 1.2903 |
| Total | | 26.6883 | 26.0838 |
| Enargy Saving % | | | 2.27% |
| 15th of December | 7:00 | 0.8745 | 0.7905 |
| | 8:00 | 1.4563 | 1.4276 |
| | 9:00 | 1.5802 | 1.5526 |
| | 10:00 | 1.6828 | 1.6762 |
| | 11:00 | 1.7706 | 1.7539 |
| | 12:00 | 1.8348 | 1.8204 |
| | 13:00 | 1.8852 | 1.8782 |
| | 14:00 | 1.8946 | 1.8825 |
| | 15:00 | 1.8704 | 1.8654 |
| | 16:00 | 1.8336 | 1.8262 |
| | 17:00 | 1.7802 | 1.7705 |
| | 18:00 | 1.7586 | 1.7375 |
| | 19:00 | 1.1366 | 0.9645 |
| Total | | 21.3584 | 20.946 |
| Energy Saving % | | | 1.93% |

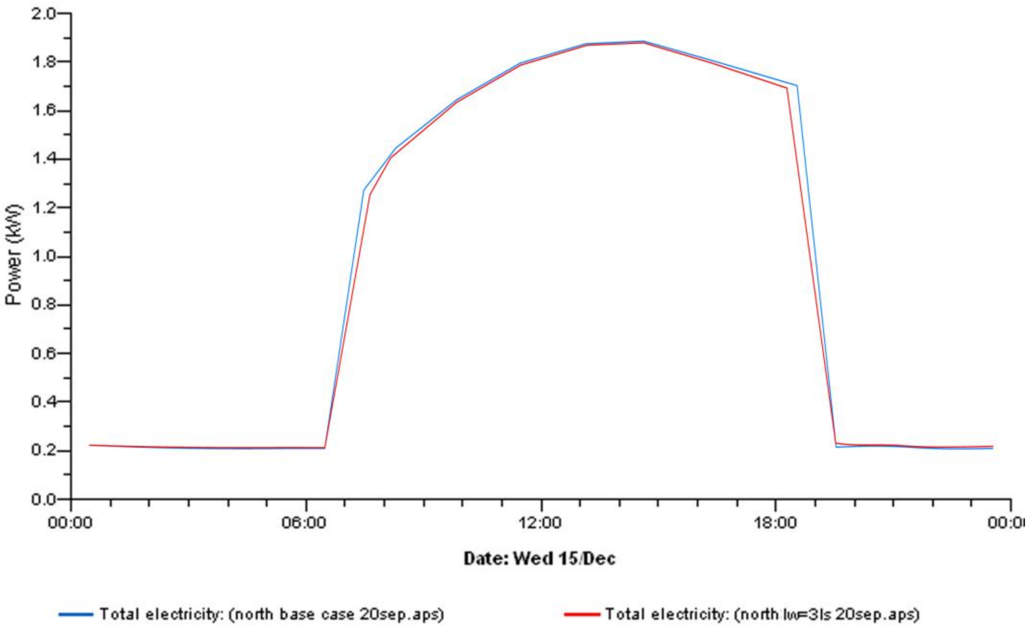


Figure D.1. Hourly energy consumptions (KW) for the louver AR=3 for North orientation on 15th of Dec.

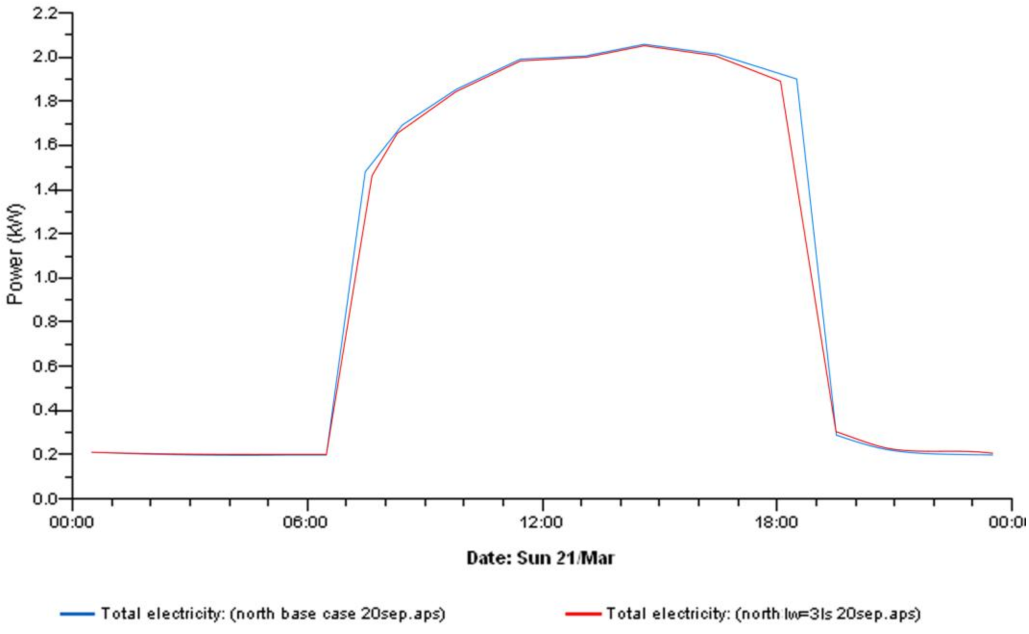


Figure D.2. Hourly energy consumptions (KW) for the louver AR=3 for North orientation on 21st of March.

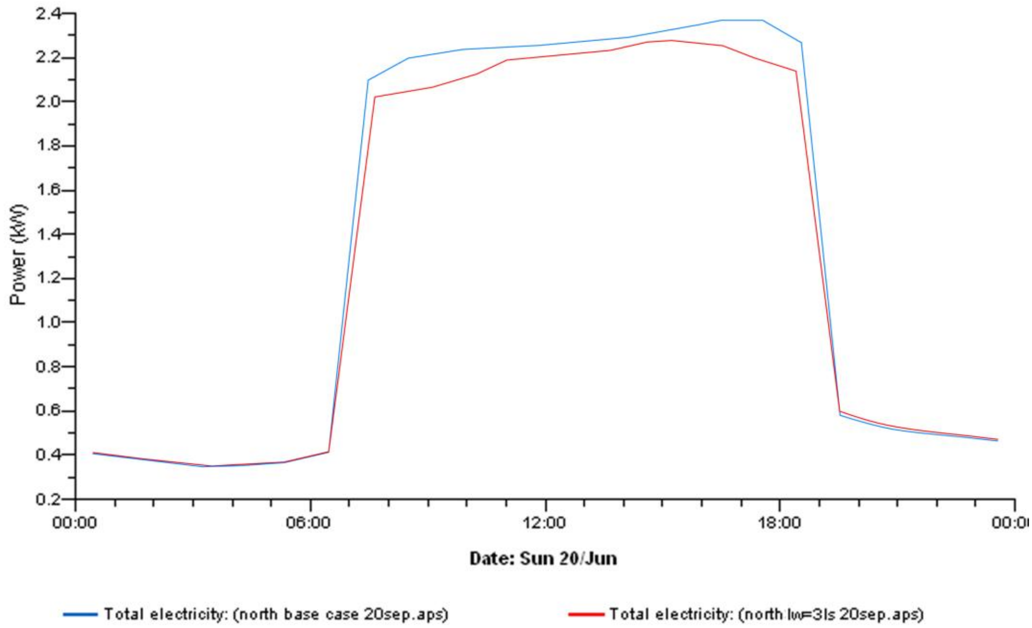


Figure D.3. Hourly energy consumptions (KW) for the louver AR=3 for North orientation on 20th of Jun.

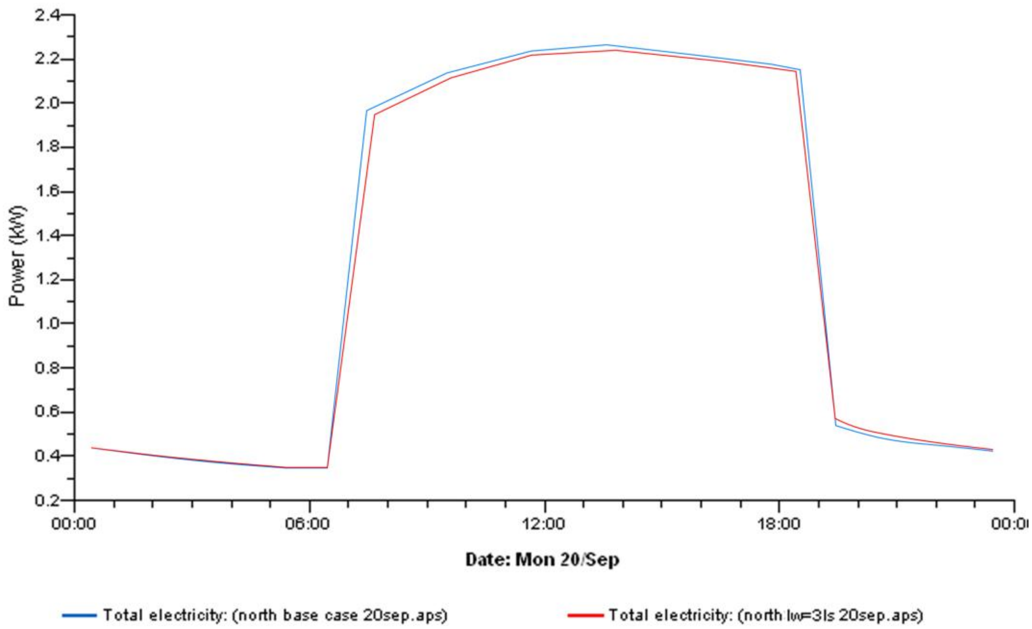


Figure D.4. Hourly energy consumptions (KW) for the louver AR=3 for North orientation on 20th of Sep.