Potential of horizontal louvers in increased energy savings in a commercial building in Dubai

إمكانية استخدام الأبجور (اللوفر) الأفقية لزيادة توفير الطاقة في مبنى تجاري في دبي

by

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Dissertation submitted in fulfilment

of the requirements for the degree of

MSc SUSTAINABLE DESIGN OF THE BUILT ENVIRONMENT

at

The British University in Dubai

October 2018

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Abstract

Building façade contributes to a major share of energy expenditure in residential as well as commercial buildings. There is a need to look for alternate options of façade design, in order to replace the glazing option contributing to greenhouse gases and global warming. This dissertation investigates the use of horizontal louvers in increasing the energy efficiency of an office cabin in Dubai, facing south direction.

The base case is simulated for further comparative simulations. Fixed and variable parameters of the simulation are investigated and simulation matrix is made for 1) Variation in Angle, 2) Variation in Width, 3) Variation in CC, 4) Variation in PV types. Each parameter is simulated with its variable options, and results are tabulated. The configuration for louvers with and without PV cells are noted separately. The artificial lighting in the cabin is linked to the dimmer sensors to a configuration that the lights will dim to 0.4% its original power if the lux level in the room is more than 500 Lux. Effect of dimmer sensor on and off is investigated in each simulation.

The dissertation creates a correlation link between the simulation results and changes in parameters. Dimmer sensor configuration shows about 10-15 % increase in energy savings than the configuration with sensor off. The most efficient case is the configuration of 50 degree louver angle, 90mm width, 90mm center to center and mono crystalline PV cells. Comparative analysis of 90mm and 150mm dimensions for both louver width and CC, highlights that if the dimensions of the two are equal, energy savings in more. This is because the louver dimensions give an optimum solution for shading profile of the horizontal louvers used on south direction.

Efficient case shows 28% more savings than base case for louvers without PV, and 40% more savings for louvers with PV. Economic case is also configured, which gives the best possible solution considering the justification of cost for the efficient case. This case configures thin film type of PV cells and shows a result of 27.88% and 34.92% more savings than base case for louvers without and with PV respectively. Payback period for efficient and economic case is 18 years and 12 years respectively.

The result highlights that using the dimmer sensors can considerably add to energy efficiency in the most economical way. After this, the priority can be given to change in optimum configuration of louver parameters. Integration of photovoltaic cells is the last option to be recommended. The payback period of this is considerably more due to the highly subsidized rates of electricity tariff in UAE. The dissertation creates a benchmark for horizontal louver configuration and its role in increasing the energy savings. This can be used as a module to recreate horizontal louvered façade on the whole building and create an impact in reducing energy expenditure of office buildings in Dubai.

ملخص

تسهم واجهة المبنى في حصة كبيرة من نفقات الطاقة في المباني السكنية والتجارية. هناك حاجة للبحث عن خيارات بديلة لتصميم الواجهة، من أجل استبدال خيار التزجيج الذي يسهم في غازات الاحتباس الحراري والاحترار العالمي. تبحث هذه الرسالة في استخدام أغطية أفقية لزيادة كفاءة استخدام الطاقة في أبينة مكتب في دبي، في اتجاه الجنوب.

يتم مقارنة الحالة الأساسية مع عملية المحاكاة. يتم فحص المعلمات الثابتة والمتغيرة للمحاكاة ويتم عمل مصفوفة المحاكاة لـ 1) التباين في الزاوية، 2) التباين في العرض، 3) التباين في CC، 4) التباين في أنواع اللوحات PV. يتم محاكاة كل معلمة بخيارات المتغير الخاصة بها، ويتم جدولة النتائج. ولوحظ بشكل منفصل تكوين فتحات التهوية مع وبدون الخلايا الكهروضوئية. وترتبط الإضاءة الاصطناعية في المقصورة بأجهزة استشعار باهتة في أن المصابيح سوف تخفت إلى 0.4٪ من قدرتها الأصلية إذا كان مستوى اللوكس في الغرفة أكثر من 500 لوكس. يتم التحقق في تأثير تشغيل أجهزة الاستشعار الباهتة وإيقافها في كل محاكاة.

تخلق الرسالة علاقة ارتباط بين نتائج المحاكاة والمتغيرات. يُظهر استخدام مستشعر باهت حوالي 10-15٪ زيادة في توفير الطاقة مقارنةً بعدم استخدام المستشعر. الحالة الأكثر كفاءة هي تكوين زاوية فتحات التهوئة 50 درجة، عرض 90 مم، 90 مم مركز الى مركز وخلايا PV بلورية أحادية. التحليل المقارن لأبعاد 90 مم و150 مم لكل من عرض اللوفر وCC، يسلط الضوء على أنه إذا كانت أبعاد الاثنين متساوية، فإن توفير الطاقة يصبح أكثر. هذا لأن أبعاد فتحات التهوئة تعطي حلاً مثالياً لمشاركة المظهر الجانبي للفتحات الأفقية المستخدمة في اتجاه الجنوب.

تظهر الحالة الفعالة 28٪ زيادة في المدخرات مقارنةً بالقاعدة الأساسية للكواتر بدون لوحات الكهروضوئية، و 40٪ من التوفير للفتحات مع لوحات الكهروضوئية. تم دراسة الحالة الاقتصادية أيضًا، مما يوفر أفضل حل ممكن بالنظر إلى تبرير التكلفة للحالة الفعالة. هذه الحالة تتمثل في استخدام نوع رقيق من فيلم الخلايا الكهروضوئية ويظهر نتيجة لمدخرات 27.88 ٪ و34.92 ٪ أكثر من الحالة الأساسية بدون ومع الخلايا الكهروضوئية على التوالي. فترة الاسترداد للحالة الفعالة والاقتصادية هي 18 سنة و12 سنة على التوالي.

وتسلط النتائج الضوء على أن استخدام مستشعرات dimmer يمكن أن يزيد بشكل كبير من كفاءة الطاقة بأكثر الطرق اقتصادية. بعد ذلك، يمكن إعطاء الأولوية للتغيير في التكوين الأمثل للمغيرات في اللوفر. تكامل الخلايا الضوئية هو الخيار الأخير الموصى به. وتعزى فترة الاسترداد لهذا إلى حد كبير إلى المعدلات المدعومة بشدة لتعرفة الكهرباء في الإمارات العربية المتحدة. تخلق الأطروحة معيارًا للتكوين الأفقي ودورها في زيادة توفير الطاقة. يمكن استخدام هذا النموذج كوحدة نمطية لإعادة إنشاء واجهة أفقية في المبنى بأكمله وخلق تأثير في خفض نفقات الطاقة لمباني المكاتب في دبي.

Dedication

This dissertation is dedicated to my parents Meena and Pratap, who have been a constant positive support throughout this journey.

Acknowledgement

This dissertation is possible with the co-operation and support of a lot of people. I would firstly like to thank the Almighty God, for giving me the opportunity and ability to complete this dissertation.

I would like to deeply grateful to Professor Bassam Abu-Hijleh for the guidance, support and for sharing his knowledge and resources with me. His timely and valuable feedback has resulted into making this dissertation into reality. I would like to convey my deepest gratitude to him for being the motivation and patience that he showed in spite of his overwhelming schedule.

I would like to mention a special thanks to Mai, for sincerely helping me with IES-VE software in spite of her own commitments.

I would like to thank my parents, friends and family who were a constant emotional support in this journey. Special thanks to Shari, Sanal, Harish, Aniket and Fatma for their encouragement and love throughout the process of writing this dissertation.

I would like to express my gratitude to Ms. Ninu Padikkala and all staff of Global Group of Companies for sharing the resources of energy expenditure for the selected office.

I would like to thank The British University in Dubai and all its teaching and non-teaching faculty for providing a wonderful learning environment and enriching library.

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1. Introduction

1.1 Overview

This chapter gives a highlighted overview of the dissertation. It traces the path on which the topic of this dissertation evolved. The basic idea of building façade is explained with respect to energy efficiency. The chapter also gives an outline of the phenomenon of increased carbon footprint and how the need for this research has taken place. The chapter gives a basic framework of how the research in this dissertation will be carried out.

1.2 Definition of building facades

Building an envelope of shelter around him is one of the primitive necessities of mankind. The reason for this was to protect him from the nature's wrath and wild beasts. The building façade traces its roots back to this natural need of human beings to separate the external environment from the internal. Façade literally means face in French and hence building façade is primarily the exposed face of any structure. In very simple terms it can be defined as the exterior envelope of the building which may or may not share the structural loads of the building but fulfills the comfort and security requirements of the inhabitants.

Cikis (2007) defines building façade as the cladding which is partially attached to the skeleton of the structure. However, Brock (2005) explains building façade as the primary weather screen barrier which is exposed as the external elevation of the building. While most of the researchers have associated building façade with the environmental barrier, some believe that it is a design component. According to Harris (1993), building façade is the finished cover of a building framework which can be constructed in a combination of material like stone, wood, glass or cement.

Irrespective of the definition coined by many researchers, the building façade continues to be one of the important elements of the building.

1.3 Glazed building facade

Curtain walls and glazed façade has become the most common façade elevation option in contemporary building construction. The technology of glass in construction field has made it possible to make cantilevered glass cubes, curved glass elevations and various other forms. Glazed façade is a lighter and sleeker face of the building which is also commercially viable. Hence the skyline of most of the metropolitans in the world is being dotted with glazed towers. Glass elevation for towers has already left its mark on the 20th Century and there seems to be no stopping in even the coming years. The glazing option is the easiest option to growing population demand. Figure 1.1 shows the skyline of Shanghai, which previously were just agricultural fields.

Figure 1.1 Partial skyline of Shanghai (CNN 2018).

1.4 Effects of glass facades on the building and environment

Last twenty years have seen the marking of glass façade fronts as a dominant element in urban skylines. The structural design of modern buildings is oriented towards making the building aesthetically light weight. The use of glass brings heat along with the light. The building works like a greenhouse and creates stress on the cooling requirements. Approximately one third of the energy expenditure of a commercial building is due to interaction of the building envelope to the outside environment (Haase and Amato 2006). The last decades of building construction did not pay heed to the disadvantages of using glass façade. But now it is important to prudently choose the usage of glazed elevations and its effects on the environment. The energy management of buildings and CO2 emission created is a concern which has to be addressed. The complex glass towers have now become major energy producers. The glass elevation not only heats up the building, but also creates a stress on the rest of the services. Cooling of these buildings take up huge burning of fossil fuels in order to make up for the HVAC requirements. The energy bills of these buildings are far more than the masonry or RCC constructions. The insulating value of glass is lower than its contemporary options. The thermal gains and losses from the glazed front of the building is the maximum as compared to any other elements of the building. Despite being aesthetically better option, the glass façade system is not a good energy link of the building performance.

1.5 Energy demands of glass buildings in Dubai

The United Arab Emirates (UAE) has seen a boom in construction the past two decades. The skyline of the country which was once a land of desert, is now hosting the tallest structures in the world. Owing to its hot and arid climatic conditions, HVAC is an integral part of any building in UAE. The country is divided into seven emirates and Dubai is one of the major one.

Dubai has become one of the most important cities with respect to global trade, economics and tourism. With the upcoming Dubai Expo 2020 in vision, the city is now growing to accommodate even more population in the coming years. The skyline of Dubai is one of the densest commercial hubs.

Figure 1.2 Dubai Skyline with glass towers (ME Construction News 2012)

As per the statistical predictions by 2011 Buildings Energy Data Book (U.S. Department of Energy 2012), Dubai has displayed an energy growth of 4 percent per year for the last six years. It is also projected that this energy demand will reach up to 5 percent till Expo 2020. The commercial building in Dubai are the major contributors to the energy demand. Fully glazed facade is a leading trend in Dubai which is contributing to more energy consumption of the city. As per the research submitted by Aldawoud (2017), the International Energy Agency IEA has forecasted the Energy consumption in UAE as given in the table shown in Fig 1.3

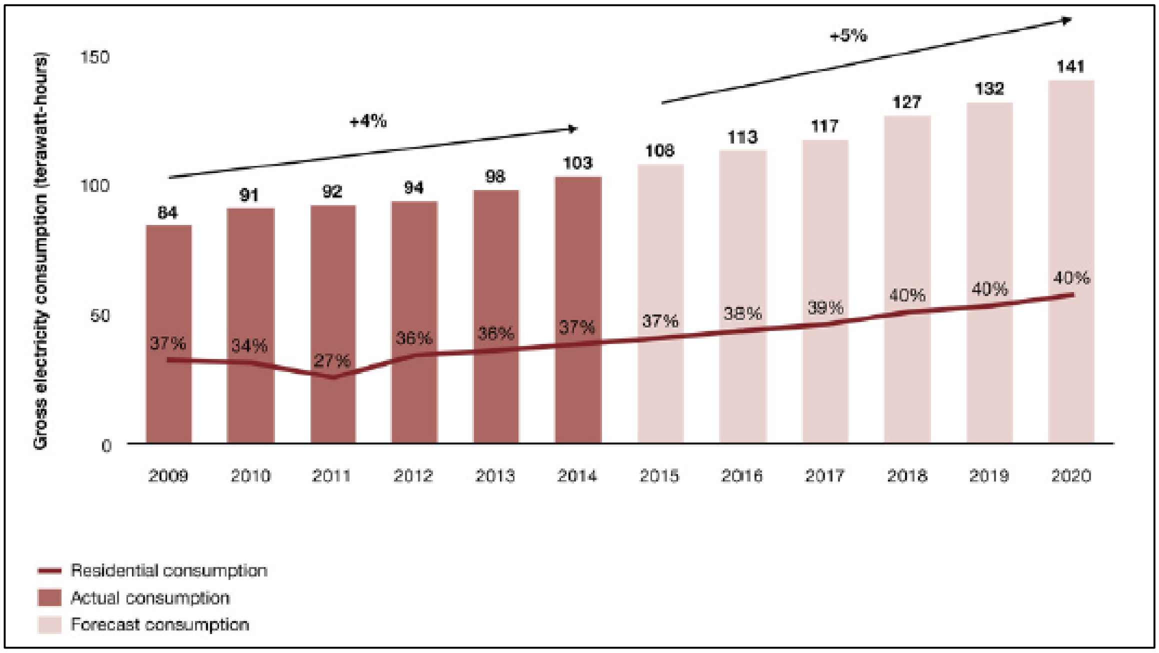

Figure 1.3 UAE electricity forecast for the next five years as per International Energy Agency (Aldawoud 2017).

As Dubai is adopting to the trend of glass fenestration to its commercial buildings, the building performance of these buildings is not efficient. Large commercial hubs in the city are being converted into energy producers. Tibi and Mokhtar (2014) have studied the rapid growth in residential and commercial sector in UAE. Their studies highlight the fact that residential and commercial buildings contribute to 68% of energy consumption of the nation. HVAC system shares almost 70% of this consumption during peak heat durations of the summer months. Glazed façades of buildings contribute to 80% of the total energy spent by the building. There is an alarming need to change the way the city is developing. Evaluating different options of elevations of the building, which are more energy efficient is a viable option to cut down on the growing energy demand of the city.

The UAE Ministry of Climate Change and Environment (n.d.) has launched the National Climate Change Plan of UAE for 2017-2050. This project focuses on managing the greenhouse gas emissions. The government plans to set clean energy targets for buildings in order to tackle this problem from the grass root level. Fig 1.4 gives a comprehensive layout of the strategies outlined by the government to mitigate and adapt newer policies by 2050

Strategy	Response	Expected Outcomes			
	As of 2017	By 2020	By 2025	By 2030	By 2050
Mitigation	2021 clean energy target at national level established	National GHG emissions management system established	Management of GHG emissions progressed	High level of eco-efficiency achieved	Robust national climate change management system in place
Adaptation	National climate adaptation policy development initiated	Climate risk and vulnerability assessment performed, immediate measures put in place	Adaptation planning mainstreamed in development policy	Continuous monitoring and evaluation to ensure evidence-based adaptation measures	

Figure 1.4 Targeted strategies for Climate change till 2050 (The UAE Ministry of Climate Change and Environment n.d.)

Managing the energy consumption of commercial buildings is the focus of the government initiative. Need to identify alternative façade options is important in order to improve the building performance of buildings in UAE.

1.6 Framework of research

This research will explore the underlying potential of sustainable facades for energy efficiency. Different option of façade elements will be discussed in course of this research, but prime importance will be given to horizontal louvers. The possibility of reducing the energy consumption of an office building in Dubai will be explored to its full potential. The research will be carried out through a framework of existing case study in UAE. Through literature review, the parameters of louvers as design elements will be discussed in detail. Energy generation capacity of the louvers will also be studied, with respect to louvers integrated with PV cells.

The research will be carried out by simulating a base case building. The design parameters will be checked in the simulation software and optimum case scenario will be generated. The energy calculation of the building will be checked by comparing the original consumption to the simulated consumption. The optimum louver design will be studied through all the simulated cases. The economic viability of proposed option will be tested through simple payback methods. Hence the capacity of louvers to minimize energy loads of a commercial building will be tested through the course of this research.

1.7 Motivation of the research

The construction in UAE is booming at an exponential rate with almost no consideration to the effect of greenhouse gases on the environment. The buildings in the city are glass facades which fail to enhance energy efficiency in the building. The use of glazing for most of the commercial building facades creates a load on the energy consumption due to high transparency and heat entrapment of glass. In the recent years, intelligent facades were adopted for the Al Bahar Towers and Hazza Bin Zayed Stadium in Abu Dhabi. The need of alternative façade to existing glazed façade fabric of the country has been the main motivation behind this research. Use of louver for reduction of electricity consumption, effect on PV generation, and overall building efficiency has been the topics of interest which led to the foundation of this dissertation. The potential of louvers in enhancing the energy performance of a single cabin can lead to creating a module to be used by the whole building.

The scenario in UAE highlights that energy consumption and greenhouse gas emission is a focal concern of the country's' environmental and infrastructure planning commission. Glazed towers in the commercial clusters of the city are adding to the energy demands of the city. This underlines the urgent need of exploring alternative façade development methods. There is a clear potential for sustainable options of façade development in the city.

Apart from the civic responsibility to create energy efficient design solutions for the city, there is also another motivation for this research. The cityscape of Dubai is slowly turning into a maze of glass towers. The architectural elements of building facades have been sacrificed in order to follow the trend of glazed buildings. Through this research, the element of façade design will be revived paying due respect to sustainability of the construction materials.

1.8 Aims and Objectives

The aim of this research is to investigate the optimum configuration of horizontal louvers used on a glazed south façade in energy saving for a commercial building in Dubai, along with the use of PV integration and dimmer sensor.

Following are the objectives of the research:

1. Exploring the energy saving potential of horizontal louvers on a south façade.
2. Investigating the energy performance of an office cabin with the use of dimmer sensors linked to its artificial lighting.
3. Establishing correlation between different parameters of the horizontal configurations and studying their effects with and without dimmer sensors and PV cells.
4. Reviewing the effects of change in louver parameters on energy efficiency of office cabin.
5. Generating a cost-effective configuration of horizontal louvers.

6. Obtaining a good balance between efficiency and economic considerations for louver configurations.

7. Establishing correlation between different parameters of the horizontal configurations and studying their effects with and without dimmer sensors and PV cells.

This research will evaluate the results of horizontal louvers in an office building of Dubai. The louver design will be varied with respect to changes in parameters. These parameters will be discussed in detail in the further chapters. Computer simulations will be conducted, for all the variations in parameters, with and without dimmer sensor. The effect of these parameters will also be studied on the louver with integration of PV cells. On the basis of the resulting outcome, optimum configuration of louvers will be selected.

The research focuses on overall energy consumption of the building which includes expenditure through lighting, HVAC, power and other energy outputs. If the research can decrease the energy consumption of the selected office building, it will prove to be a successful attempt within the boundaries of research.

2. Literature Review

2.1 Overview

This chapter puts together all the research material related to building facades. It reviews the papers presented in the past which have highlighted the role of static or dynamic facades for energy efficiency. The focus of this chapter is to understand the scope of research done and create a boundary for the research presented in this paper. Energy efficiency has been a topic of tremendous focus throughout the past few years. This chapter highlights the past studies related to louver strategies for reducing energy consumption.

2.2 History of Building Facades

The building façade primarily evolved from the need of mankind to protect him from the external environment. Slowly the form of shelter created began to change as technology advanced. The medieval era saw the usage of stones as the main structural component of the building. Gothic architecture developed during this time. The use of cast iron and glass was experimented to span larger heights of this building. Huge openings were constructed to give an intimidating feel of the construction. The tall spires, towers and decorative elements were the essence of Renaissance architecture. Figure 2.1 shows one such example where external façade was a decorative icon of the structure which symbolized the function of the building.

Figure 2.1 La Sainte Chapel in Paris showing medieval building facade (Cikis 2007).

As industrial revolution took a turn, it changed the face of iconic medieval structures. Buildings started to cater more to its usage and lost its requirement of symbolism. Similar type of elevations was generated to cater to the growing population in the cities. Figure 2.2 shows one such building from this era. Urbanization gave monotony to the cities and started turning them into a concrete jungle. Village clusters of spacious housing were replaced by urban sprawls. The façade of the building became a repetitive entity floors stacked upon each other for making maximum use of the floor space area. This was when the foundation of commercial buildings was laid. With the sector shifting to more industrial than farming, the need of massive office spaces was created. Buildings which could accommodate more number of people meant that the building had to be multi-storied.

Figure 2.2 Masonic Temple (Cikis 2007).

As technology advanced in the fields of building construction, glass façade began to be replacing masonry structures. Office buildings made use of the glass and steel construction, so that the building could get in maximum of sunlight. Bigger sized windows were experimented with and the technique of curtain wall was put to use. According to Haase and Amato (2006) the glazed façade developed from the necessity of constructing buildings which made use of natural light. One of the oldest buildings to boldly make use of aluminum and glazing for the external façade was the Hallidie Building. Figure 2.3 shows this structure which was constructed in 1918.

Figure 2.3 Hallidie Building (Cikis 2007).

The architect of this building was James Polk who brought the suspended glass systems to life. During this period a lot of glazed facades were experimented with. With more advanced curtain wall systems being fabricated, the face of concrete jungle began to be changing to glazed facades. The external façade enabled maximum light in the building. Cooling of the buildings was carried out with more efficiency and HVAC systems also developed to facilitate the glazed façade.

Dynamic facades became the new face of construction in the recent years. An effort was made to use adaptive façade to considerably enhance the building performance of a building using innovative design principles. A good example of such kinetic façade structure is the Al Bahar Towers of Abu Dhabi, in Fig 2.4. Architect Abdulmajid Karanouh (Aedas) designed the twin buildings in Abu Dhabi that incorporate adaptive façade elements and automated dynamic solar screens.

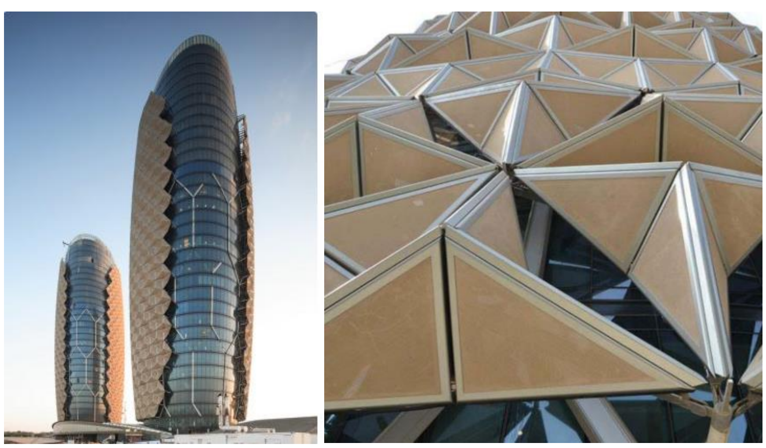

Figure 2.4 Al Bahar Towers Abu Dhabi, (Durston 2013)

2.3 Shading options for building façade

Various facets of building facades have been explored by researchers. Building facades can be widely classified on the basis of the following shading options: 1) external louver shading, 2) internal blind shading and 3) electro chromic/ film shading. Kim et al. (2017) researched on horizontal shading devices used for passive control of buildings in South Korea. The research was carried out in fulfilment of green architectural amendment in South Korea in May 2015. Evaluation methods for various parameters of horizontal shading were established. This study investigated the effect of horizontal shading on the lighting, heating and energy performance of a room. The investigation highlighted that longer the horizontal shading device lesser is the indoor day light. This creates stress on the artificial lighting system. It was also studied that modulation in HVAC and lighting consumption led it higher energy performance of the building. The length of horizontal shading device in comparison with window height on the south and west facade was studied. The result showed that horizontal shading device led to lesser solar radiation in the room. It was analyzed that the lighting performance remains unchanged, heating performance reduced and energy performance increased due to application of horizontal shading, as compared to the base case consumption. This research shows that shading devices creates an impact on energy consumption, and can be used for energy performance enhancement, as aimed in this dissertation.

Al-Tamimi and Fadzil (2011) investigated the use of shading devices for reducing temperatures in tropical buildings. This research used IES modules of Apachesim, Radiance and Sun-cast for thermal, lighting and solar shading analysis respectively. A base case unit was modelled with units on each side to simulate a high rise building. The width of shading device was fixed at 600mm in order to achieve optimum day lighting, aesthetics consideration and view angle requirement in the model. The Egg crate, combination of shading device was most effective in reducing the discomfort hours and stabilizing the temperature below 28 degree Celsius. The result showed 26% improvement in unventilated conditions and 4.7% improvement in ventilated conditions. The potential of curve shading, vertical shading, horizontal shading and egg-crate shading was studied by simulating these strategies in IES-VE. It was highlighted that egg-crate can reduce the solar heat gain in tropical regions. The position of louvers and their widths can highly influence the heat gain the room. Hence these parameters will be investigated in through this dissertation.

Evola, Gullo and Marletta (2017) researched on enhancement of thermal and visual performance in glazed buildings by the use of shading devices. This research investigated various shading devices in commercial building in Italy. A balance between indoor luminance and thermal comfort was achieved within boundaries of the building regulations in Italy. Three types of design proposal were executed namely external roller blinds, integrated roller blinds and external solar films. A control strategy was applied to the shading devices if the window radiance is more than 200 W/sqm and at 26 degree Celsius internal temperature. In this case the blinds (external & internal) were shut down. Each of the roller blind parameter was simulated to 29 different categories depending on colours, positions, air gap and transparency. The widths of blinds were in range of 2mm to 3mm, slate separation at 25mm, and angle of slate at 45 degrees. The results show that external blinds perform better on south facing glazed façade, whereas solar control films perform better on west facing glazed elevation. The need of control systems to modify the indoor air temperature is stated in order to improve thermal comfort. This research also highlights the parameters of louver center to center, width and angle to determine the optimum configuration, which will be used in this dissertation. It also highlights the fact that different shading strategy can work best for different façade orientations.

Khoroshiltseva et al. (2016) researched on a multi objective approach algorithm to design shading devices which show more energy efficiency. This study was used as a renovation model for the existing residential buildings in Madrid. The research developed an algorithm which can consider and generate solutions on the bases of occupant comfort level and energy efficiency. A shade area of 7.84 Sqm was found to be the optimum solution which gave 20.19% reduction in heat gains. Shading area was varied in its parameter from 5 sqm to 8 sqm and the effects on heating consumption were analyzed. The study used variable parameter of shading device size and highlighted that change in size of shading can bring about increase in energy savings. Hence the parameter of shading dimensions will be investigated in this dissertation.

Touma and Ouahrani (2017) studied the potential of shading and daylight controls in glazed buildings of Qatar. The shading device used was 'brise soleil' fixed at 90 degree with vertical which saved 18.6 percent energy. On the other hand fixed blinds resulted in 20.6 percent energy savings for south facade. On the northern facade this design strategy showed only 7-9 percent range of savings. Incorporation of dimming control in the artificial lights led to 26.1 % of energy savings. The risk of glare was also analyzed for north and south orientation with the use of shading and lighting control. The design strategy completely removed glare from south and north direction. The application of brise soleil and fixed blinds on the south elevation showed a result of 18.6% and 20.6% respectively. Daylight control strategy gave a result of 26.1% increased efficiency in energy consumption. The research took into consideration energy savings as well as glare control. It also compared external and internal shading strategy and drew a comparison for various orientations. This dissertation will investigate the effect of dimming control strategy on similar lines.

Atzeri et al. (2013) investigated the comparative performance of indoor and outdoor shading devices in Italy. A comparative co-relation between orientation, glazing types and location of shades was established. The energy efficiency, thermal and visual comfort were considered as the parameters of evaluation. The window sizes are varied in the range of 13.5 sqm and 22.5 sqm area. Distribution of window is taken to be on South, East, South

+North and East + West directions. Shadings are considered to be high transmittance roller shades and low transmittance roller shades. The results show that deployment of blinds on the south side gives a reduction in glare and increased energy savings. The study highlights that internal shades give increase in cooling loads and does not give subsequent decrease in heating loads. However, the external shades give reduction in cooling load and not much heating loads are slightly increased. This shows that external shading devices work more efficiently in this case than internal shading devices.

Palmero-Marrero and Oliveira (2010) evaluated the energy efficiency of louver shading in buildings located in Mexico, Cairo, Lisbon, Madrid and London. The research analyzed the use of horizontal and vertical louvers to bring about comfortable indoor environment and energy savings in each of the cities. In northern hemisphere the horizontal louvers decreased the solar gain on south elevation. On east and west elevations the horizontal louvers didn't create a major impact. Hence the vertical louvers were deployed on east and west facade. The louver width was taken to be 25cm, however 10cm width was also stimulated. The latitude and louver inclination showed an interesting co- relation in contributing to energy efficiency. The key findings of the study were that vertical louvers were effective for east and west façade, whereas horizontal louvers for the south facade. Change in louver inclination, number of louvers, spacing between louvers and position of louver were the important factors controlling energy efficiency. Thus these factors can be used as variable parameters for this dissertation. The research also highlighted the importance of geographical location in the energy consumption of a building. This dissertation will create a strong link between the shading device used and its justification with geographical position.

Shahdan, Ahmad & Hussin (2018) has investigated the strategy of external shading proposal for reduction in solar gain and glare in a school building. Different types of shading device like horizontal louvers (single, double and inclined double), vertical (single, slanted) and egg-crate type were analyzed through simulation process. Variable and constant parameters were distinguished before the simulation process. The results of the simulations showed that egg-crate system was the most optimum configuration for enhancing the energy efficiency in hot and humid climate. The study does not vary the size or depth of the shading devices, and recommendation has been made to study this further. These parameters are taken into consideration as knowledge gaps for this dissertation and framework is laid out accordingly. The study showed investigations of louver devices made in March and September. The electricity consumption was in a range of 25 MWh to 45 MWh. Egg crate system showed consumption of 25MWh, horizontal louvers gave a result of 30 to 42 MWh, whereas vertical fins gave a result of 40 MWh in the month of March. This consumption dropped by 3 to 4 MWh in the month of September.

The Karlsen et al. (2016) developed a solar shading control strategy for commercial buildings in Denmark. Physical experiments were performed in a test room to verify the strategy and it was further supported by simulations. This study was a combination of simulation, occupant survey and physical experimentation. The study highlights the need of having 1700 lux vertical eye perception and 1900-2100 lux horizontal desk luminance for avoiding excess glare in work space. A solar shading proposal is given in the study. A control algorithm strategy is combined with tilt angle as control strategy and 1700 lux vertical luminance is set as standard for sensor activation. The importance of integrating control strategy to existing solar shading is investigated.

Hien and Istiadji (2003) studied the effect of horizontal shading devices in commercial building of Singapore. The studies show that seven proposals of shading designs have various impacts with respect to daylight and internal temperatures of the building. The design of horizontal shading was varied from louvers, solid concrete shading, green roof shading to step light shading. The investigation parameters were light distribution, glare, illuminance, ventilation and air flow. Horizontal shading devices reduced the temperatures to 1.3% to 2.8% in an overall range. This study validated the results by an actual field experiment. The study shows that a lot of internal and comfort parameters can be focused and modified by the simple use of shading devices on the external façade.

2.4 PV cells and Light Dimmer sensors

Building Integrated Photovoltaics (BIPV) has gained popularity all over the world. BIPV has the potential to convert any building façade as a medium to generate electricity and contribute to performance enhancement of the building. Aesthetics and environmental considerations of design can be retained in addition to making the building energy efficient. BIPV needs to be adopted individually to a particular geographical location, in order to test its productivity for that particular scenario. A lot of research has been carried out to integrate PV cells in the geographical and climatic conditions of UAE.

Attoye, Aoul and Hassan (2017) researched on the potential of BIPV in façade development of buildings in UAE. The studies summarized that there is a possibility of 2-80% performance enhancement in energy consumption of buildings with the use of PV integration. This study made a comparative analysis of various BIPV strategies used at various locations. It underlined the fact that a general conclusion of effect of PV cells cannot be made unless the particular building is tested at that location and resources. Customization of BIPV in order to incorporate the building elevation played an important role in overall social acceptability of the PV concept. A lot of research on PV integrated with building façade in investigated. Some case studies which integrate PV at module, façade, geometrical and ventilation levels are described with reference to architectural and strategy potential. The research is tabulated as non-ventilated and ventilated buildings and energy savings of each are compared. The zig zag geometry capture showed 43% and 53% reduction in grey and white colour of PV panels. Conventional façade design gave 54 %

energy savings. This study explored the potential of PV cells being modified in its function to suit the needs of design and energy efficiency.

Katanbafnasab (2010) investigated the potential of BIPV and Electrochromic (EC) glazing in commercial buildings of UAE. The comparative analysis of both these strategies shows that BIPV works the best for east, south and west façade whereas EC glazing yields good performance on North façade. The deployment of BIPV on south façade gave maximum energy savings of 20% as compared to other elevations which ranged in 15 %. Electrochromic model showed very poor results for south orientation with -2% savings as compared to north orientation of 7%. This study also reveals that light control dimming system integration with BIPV shows higher energy efficiency.

Efficiency of PV cells depends upon cell temperature, orientation, energy conversion potential and component efficiency (Jung 2014). Due to these factors of PV cell efficiency, it is important to test each parameter of shading device to check optimum performance enhancement. Power output and visual comfort are the two important factors to be balanced while integrating PV with building façade. Acceptable work desk luminance is necessary along with energy efficiency. The study showed that louver integrated with PV was more efficient than wall mounted PV by 48%. This will be used in this dissertation to investigate more potential of louvered PV in reducing cooling loads of the building.

With the introduction of automation in building technology, there has been a shift towards dynamic control systems for all the modules of building façade. Dynamic control systems change their function or intensity based on the real time situation, rather than following a set algorithm based on time. One such dynamic system is dimmable light sensors. Hammad and Abu- Hijleh (2010) investigated the use of external louvers in an office building of Abu Dhabi. Vertical louvers were simulated with the use of light dimming control strategy. -20 degree angle was shown to be the most effective for south façade while comparing the results of vertical louver simulations. The east and west elevations showed 20 degree angle to be the optimum. Fixed shading devices gave lesser energy savings than dynamic louvers, but the economic impact is well justified to select fixed louvers as the efficient solution. Using the dimmer light strategy even without using external facades was also a proposed option through this study because it led to considerable energy savings. The use of louvers on east and west façade was proved to be unjustifiable as compared to the investment but south façade showed good result in vertical louver shading. This will be taken as a basis for investigating this dissertation with respect to artificial light linked to dimmer control system. Since vertical louvers are already investigated, this dissertation will analyze the effect on horizontal louvers linked to artificial light dimmers.

(Roisin et al. 2008; Ihm, Nemri, and Krarti 2009) This study was made using sensor devices and computer simulations. The dimming control strategy gave reduced lamp output when the illuminance level exceeded the control value. The cost analysis and energy consumption was studied in detail. The performance of sensor operated light as compared to manually operated light was 27% and 44% respectively. Centralized DALI – compatible ballast controller was preferred rather that embedded systems. But this is only applicable if a single controller manages 4 light fixtures. South oriented office in Athens gave a better energy output than north oriented office in Stockholm with comparative energy savings of 61% and 45% respectively. For single office, the complete shutdown of lights was a preferred control strategy rather than dimming control which was optimum for larger work spaces. This study evaluated the use of dimmer control strategy and strongly linked it to energy efficiency. This dissertation will use dimmer sensors in accordance to south facing elevation and analyze the results of the same.

Li, Lam and Wong (2006, Cited in Jung, 2014) studied the use of sensors to reduce energy expenditure by 33% based on field study. The study highlighted high glare effect which led to manual override of the system by the occupants. The study reported that open plan offices saved 1.1 to 1.7 kWh using daylight control strategy. Annual savings was analyzed to be 365kWh. According to Murdoch, Harrold and Goldsbury (1996, Cited in Jung, 2014), the optimum light level in a commercial environment is considered to be 500 lux. An amalgamation of natural daylight, artificial lighting and dimming sensors, can help to cut down the excessive light in an office. It can also reduce visual discomfort and excessive glare

2.5 Knowledge Gap

There has been a lot of research on various types of shading devices and their efficiency tested in the Middle East and rest of the world. The effects of louvers is bested tested at a particular location and can differ with respect to a lot of parameters. Hence it is important to make a comprehensive simulation program to test each parameter with all its capacity. The previously studied research showed that it is established that south façade has the most potential to consume building energy. At the same time it is an optimum elevation to deploy PV strategies as well as test daylight control strategies. The effect of louvers on other facades have been shown to be lesser in comparison with south façade. Hence this dissertation will use south façade orientation of office for further investigating the louver strategies.

The previous research on louvers and shading system, integrated photovoltaic and dimmer sensors has been analyzed in detail. The effect of these three in correlation to each other is a vital part of the study conducted further in this dissertation. The economic justification and efficiency comparison will show which of the three strategies are the most optimum to use. The solution for energy savings will be thus given in increasing order of the most easy to employ and efficient strategy first. A number of simulations will be carried out to investigate whether louvers can be used to enhance energy performance of a cubicle. For a particular orientation in Dubai, the optimum conditions of louvers will be framed out. The parameters of louvers such as slat angle, width, center to center are an integral part of energy calculations as shown in the previous research. Hence all these parameters will be simulated in a considerable range to get the most optimum output. The cost impact and economic feasibility is also an important part of this dissertation which will be attended to. Most of the previous research carried out does not clearly state the cost analysis of the proposed shading device. The balance between energy performance and economic feasibility is an important area of study which will be covered. The previous research gives a scope to explore various parameters of horizontal louvers simulated with same standard comparisons. Along with this, PV integration and dimmer sensors will also be linked in this dissertation. All these factors will be analyzed individually and with relation to each other and results will be analyzed.

3. Methodology

3.1 Overview

This chapter highlights the methodology selected for this research. The various types of methodology will be compared in parallel to find the best solution for the course of research. Similar research conducted on this methodology will be studied in detail, to highlight the pros and cons of each type. The steps of the research will be explained in further detail through this chapter. This chapter aims to define a path of research and methodology used for it.

3.2 Analysis of various methodologies

A number of papers were studied in order to draw light on the scenario of energy efficiency of building façade. The methodologies used for the research includes physical experiment, numerical validation and computer simulation. The review of these papers focuses on how the methodology gave justice to the research at hand.

3.3 Computer Simulation Methodology

Hammad and Abu-Hijleh (2010) analyzed the energy savings in Abu Dhabi commercial building. The study made a module to represent the whole building, and the simulations were carried on this module. The simulations were carried out in IES-VE software. Orientation of vertical louvers, the slat angles and shading co-efficient was simulated and the results were compared. The study also linked the artificial lights in the module to dimmer control strategy. It established a strong link in between dimmer sensor and energy savings and compared it to results of dynamic facades. The sensors were created using RADIANCE application in IES-VE.

Sharaidin, Burr and Salim (2012) integrated the parametric modelling and façade to develop an energy efficient solution. The research analyzed features of kinetic façade such as rotation, elastic, sliding, self-adjusting and retracting. A building in Melbourne was simulated using Grasshopper with Ecotect, Galapagos. The study used some fixed parameters of illumination and some variable façade parameters. Required illumination was obtained with the activation of kinetic façade which changed its shape. The use of dynamic design was studied for improved energy savings.

Huang, Liu and Liang (2015) tested the performance of a shading device on a building in Taiwan to increase the thermal comfort in the building. The proposed design considered a buoyancy driven shading device simulated in Energy Plus. The base case of this study considered energy efficiency of static and exterior blinds. The shading device also reduced the glare issue and gave efficient daylight usage in the interiors. Number of simulations were carried out in the model, to test all the results in parallel.

Monna and Masera (2010) investigated the energy efficiency of office building in hot climate of Saudi Arabia. The parameters analyzed were thermal comfort, humidity and solar radiation. The framework of the study focused on design decision, pre-processing and energy analysis of various proposals. The results were evaluated on the basis of thermal and visual comfort, outdoor views and energy savings. The glazing transparency and shading orientation was changed in the simulations. The results focused on evaluating the façade efficiency with respect to energy savings from each simulation. The role of mechanical and night ventilation in reducing the cooling loads of a building were also evaluated using TRYNSYS. The different shading strategies used were vertical louvers, external projections, internal projections and horizontal louvers. Glazing parameters and thermal mass was also investigated with simulations. Building façade envelope played an important role in reducing the energy consumption of the building. Also, the need of early design intervention was highlighted.

Sheikh and Gerber (2011) studied the energy savings and daylight automation of a building. The study focused on proposal of semi- automatic and fully automatic louvers for energy efficiency. The simulation was carried out through Grasshopper, Rhino, Galapagos and DIVA. The 3D based simulations were carried out in Rhinoceros while graphical automation was carried out in Grasshopper. Daylight analysis was evaluated in DIVA software. The result comparisons were done using Radiance, Daysim and Evaglare software. Control strategies for occupant and environment change were simulated and the movement of louvers maintained the optimum illumination. The use of dynamic louvers in increasing the energy savings was highlighted the study.

Sheikh and Kensek (2011) analyzed the energy and daylight performance of building by use of Rhino, Grasshopper and Galapagos. Modelling was carried out in Rhino, parametric interface was evaluated in Grasshopper, whereas Galapagos was used for problem fixing. The daylight analysis was varied out in DIVA. The façade used independent tilt angles in order to bring about energy efficiency. Light penetration, daylight distribution and glare control were the parameters which were focused on. Early intervention of modelling, made it possible to explore various options. Variation in selected parameters is possible by Computer simulation techniques.

A window model was simulated by Gouri Datta (2001) in order to explore the effect on thermal comfort. The window was integrated with a shading device which was simulated in TRYNSYS software. Four different locations in Italy were considered for this study. The slat angles were varied with respect to locations and results were tabulated accordingly. The study focused on providing geographically distinct shading parameters for each location tested. Computer simulation made it possible to test results at various locations at the same time, and explore potential of shading device on façade.

Pros:

This is the most commonly used method when it comes to façade design and energy efficiency. Due to development in technology and software, this method has been dominating the research in past few years. A real time scenario can be simulated in computer application. These simulations can be run for any weather condition, throughout the year, for any location preferred. This makes simulation methodology, the most convenient option to be used. The biggest advantage of computer simulation is the fact that the parameters of research can be modified at any point of time. The computer will revise its parameters and generate the new result within no time. Time and effort invested in this methodology is far less as compared to the accuracy of the results obtained. For the purpose of façade treatment research, the computer simulation is the preferred options by individual researchers who are bound by time and cost limitations.

Cons:

Computer simulations are completely generated by machine; hence a proper validation is required. A base case scenario has to be simulated in the beginning of the research and has to be validated by either real energy bills, or physical experiment. The machine and software used for computer simulation has to be used efficiently by the user, to generate the optimum results required.

3.3.1 Physical Experiment and Survey

Goia et. al. (2013) studied a glazing prototype which improved the energy performance of the base case study. The hear flux, irradiance and thermal values in the room were measured by installing different prototypes with different materials used for glazing. The experiment was carried out by testing, data analyzing and performance evaluation. As a result of this experiment it was validated that the prototype TT+PCM(IN) was more energy efficient as against the contemporary triple glazing option.

Elarga, Zarrella and De Carli (2016) used the numerical methodology to calculate the integration of photovoltaic cells in a building façade. The energy generated by the PV cells was numerically calculated and validated against the actual bills of the building. Through this experiment the inner layer glazed façade and cavity ventilation was tested for solar gain capacity. This experiment was calculated for three different locations of Venice, Abu

Dhabi and Wurzburg. The measure and calculated data was then validated using TRNSYS 16.1

Bakkera et al. (2014) experimented on the effect of occupant satisfaction by automated facades. A group of people were selected to survey and test the pot occupant evaluation of dynamic façade installed near a work desk. Manual override option was also explored in this experiment. The physical experiment brought to light that the noise of moving façade created a disturbance to the occupants. Manual override option was referred by the survey group than automate proposal. The research concluded with the face that a control strategy for any designed proposal is necessary for occupant satisfaction.

Pros:

Laboratory based experiments or real life experiments are the basis of this methodology. A hypothesis is validated using field work and real conditions. Since the parameters to be used are real, it is efficient to make changes in the parameters as per research requirement. The accuracy of this methodology is the most real, due to actual instruments used for mock up. In case of experiments conducted on facades, the actual weather conditions can be aptly noted in physical experiment. The practical difficulties of the design solution can be clearly understood in real life mockup.

Cons:

Physical experiment takes the longest time out of all options. The weather conditions of the whole year cannot be taken in a short time. Changing the parameters or design at a later stage, needs a change in the whole set up of the mockup. Human errors and instrument defects need to be thoroughly checked in order to get accurate results. The experimentation method used in reviewed papers, has been carried out under a specific Laboratory with controlled conditions and instruments. For the purpose of this research, physical experiment is a possible but time-consuming option. Also, that economic investment for such a mockup is more than the other methodologies.

3.3.2 Numerical Methodology

Liu (2014) studied a simplified numerical model which analyzed a kinetic glazed façade. The first part of this research included development of a numerical interpretation of the automation system used for the research. This was validated with computer simulation on BSim software. A full-scale model of the glazed façade was also created at the Aalborg University in order to test it in physicality. This gave a real-life validation to the proposed solution.

Pros and Cons:

The numerical method makes use of mathematical equations to validate the hypothesis if the research. This methodology is applied by a couple of reviewed papers. The numerical methodology has to be validated by either experimentation or computer simulation.

It is a complex methodology to use between various parameters of façade design. Hence it proves to be a limitation for the course of this research. Numerical method proves to be economically easier option, but the results are limited within the boundaries of mathematical equations only. Real or simulated graphical scenarios cannot be comprehended by the use of this method.

3.4 Selected Methodology

After comparative analysis of the three methodologies and thorough review of the research papers, it can be confirmed that the research methodology used for this project will be computer simulation. This method will make it easier to simulate the weather conditions in Dubai throughout the year, in a limited amount of time. Also, being a commercial building, the selected base case can be easily simulated in computer for better results. Physical experiment in this case will require authority approvals from the building management. Numerical method is too complex for the research topic selected. The parameters of louvered façade will be changed a number of times, to get the optimum result. Controlling this in mathematical equation will not be an efficient solution.

Computer simulation will also make it possible for the parameters of louvers to be changed over course of time. Dimmer sensors and PV integration can be efficiently checked in simulation. Comparison of how different types of louvers function, can be studied in detail by simulating these scenarios on computer. The reviewed papers have made use of Ecotect, TRNSYS, Grasshopper, Design Builder, and IES-VE in order to simulate the research.

This research will be carried out using the software IES-VE. Integrated Environmental Solutions- Virtual Environment (IES-VE) is software which generates simulated feedback on a model created in the application. It also suggests the user, sustainable options in order to comply with LEED and BREEAM rules. The software can generate results for any location in the world. This software is ideal for generating louvered façade design for a commercial building and simulating it throughout the year.

The following applications of IES-VE will be explored during the course of this research:

1. The basic model will be generated in ModelIIT
2. Thermal Analysis will be run in ApacheSim
3. Shading will be analyzed using SunCast
4. Artificial lighting options will be checked using Radiance and FluxPro

The software will be validated by comparing the simulated and actual energy consumption of the selected office cabin, with a maximum variation consideration of 4%. Only after validation, the base case scenario will be taken to be a comparative framework for rest of the simulations. Further simulations will be carried out to design an optimum solution for louver configurations.

3.5 Selected base case for research

An existing building in Dubai will be selected for the purpose of research. The Al Mezan building located in Muhainsah 4, Al Quasais is the selected base case. This commercial tower of 9 floors houses a lot of offices including Commercial Bank of Dubai and FEWA Head office. The building façade has glazing on all the four elevations. The office of Global Group of Companies occupies 52 Sqm on the third floor of the Al Mezan building. The office uses ducted HVAC system with Air handling unit. The light system in the office is a combination of CFL and CFL grid system. A single cabin uses on an average 2- 3 CFL tubes. The office of Global Group of Companies occupies one fourth of the floor area. The office consists of a reception, open plan working space, 6 individual cabins, conference room, 2 washrooms and pantry area. A single cabin of this space will be used for the purpose of this dissertation.

The existing office does not have any smart systems installed in it. The lights and thermal control are manually operated and without any sensors. The office has vertical blinds in some of the individual cabins to restrict the glare from south facing window.2 cabins and one open plan office has external windows, rest all the working spaces are dependent on artificial lighting. Use of day lighting in the office is very minimal, and there is no control on the dimming, glare or lux levels on the working space. Figure 3.1 shows the external south facing elevation of the building, and figure 3.2 shows the location of the building on Google maps.

Figure 3.1 Al Mezan Building, Dubai. (General Construction Company 2018)

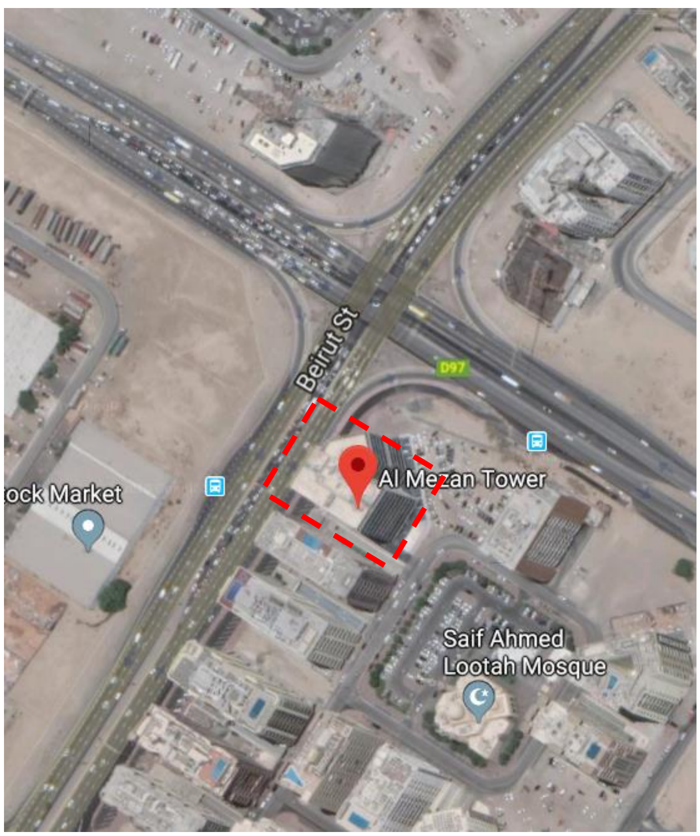

Figure 3.2 Location of Al Mezan Building, Dubai. Google Maps (2018)

This building is selected because of the author has access to one of the offices in this building. The building has a heavy use of glazed façade. The location of this building is within a cluster of mixed used towers. The tower is located at the prime location of Beirut Street. The front elevation of the towers is facing the South orientation. Since the building has a lot of different offices, the energy consumption of this building is very high. The building consumes energy for 6 days of the week, 12 hours for 365 days a year. Hence there is a potential to design energy efficient façade for the selected tower.

For the purpose of this research, a single office room will be simulated out of the whole building. The proposed façade design will be checked for this particular office cabin and will be simulated to check its annual performance.

3.6 Steps of research

The literature review and methodology for the selected research has been explained in brief. A case study of Al Bahar towers has been carried out in the literature review, in order to represent the idea of dynamic facades in the selected location. The selected methodology type is computer simulation. The overall framework of the researched will be as follows:

Step 1: Layout of the selected cabin from the office building, its location and dimensions. Layout of the furniture and details of occupancy, and details of electrical equipment, lights and energy sources will be discussed.

Step 2: Creating a base case model of the cabin, with glazing façade. Adding building construction components, internal loads and energy profiles will be carried out. Simulation of base case will give the simulated energy consumption of the model. Comparison of simulated base case energy expenditure with the actual energy expenditure of the office will be carried out. This will validate the use of IES-VE software for the further research. The simulated energy will be compared with a variation allowance of 4 % from the actual energy expenditure reflect in the bills.

Step 3: The validated base case consumption will be used as a basis of comparison for other simulations. The objective of further research will be to minimize this base case consumption to an optimum value, by using louvers with and without PV. Dimmer sensors will also be added and tested along with louver parameters. This will test the effect of sensors linked to artificial lighting and result in energy consumption.

Step 4: Simulation of various cases will be executed by modifying the louver parameters. Each case and the variable parameters are given in detail in the Simulation matrix in Chapter 4. Tracking angle matrix will be generated for studying the effect of dynamic louvers of energy consumption.

Step 5: Efficient parameter from each case will be generated. This will give the efficient case. Correlation between different aspects of parameters will be established and results will be discussed in detail. Effect of PV cells and dimmer sensors will be investigated with respect to change in louver configurations.

Step 6: Economic and efficiency feasibility studies will be conducted. Simple payback period of both the cases will be generated and compared. Justification of use of PV cells and dimming sensors will be evaluated in accordance with percentage savings in electricity.

Step 7: Concluded results of the research will be tabulated. Optimum design of louvers for energy efficient façade will be established. Discussion of louver design with respect to variable parameters will be explained in brief. Further recommendations in scope of this research will be given for future research,

4. Building the Simulation Model

4.1 Overview

This chapter describes the detailed process of creation of the simulation model in the software IES-VE. The validation of IES-VE is necessary for the complete justification of the results obtained in the simulation process. The simulation matrix and format of tabulation is explained, which becomes the basis of result tabulation.

4.2 IES-VE: Validation of Software

Computer simulation is a software generated algorithms and equations which are used to analyze the working of the built model. Sargent (2009) studies the verification of simulation models and recommends a validation. The study shows that a model may be valid for a set of questions but may not work for another set of questions. Hence the accuracy of the results must be checked to validate its credibility. There are aspects of validation processes which include the following:

1. Validation of the software:

   The software of IES-VE has been checked and authorized by Communities and Local Government (CLG). It has also been validated against global standards of ASHRAE 140: 2001, 2004, 2007, 2014 (IES n.d.). The link for these results can be viewed on www.iesve.com.

2. Validation of author's knowledge about the software:

   The author attended various educational sessions conducted by IES representatives. The software was well practiced before starting the simulation. The modeling framework and results were reviewed by a technical advisor and the results were also verified with similar cases from literature review.

3. Validation of values of simulation:

   The values of simulation have to be compared to an actual data, to check the validity of the simulated software. The author has access to one of the office cubicles of the building. This cubicle was simulated in the IES model, and the energy consumption was analyzed. This simulated energy consumption was then verified with the actual electricity bills of the office. The comparison of both the results will be included in the section 4.4 of this chapter.

4.3 Simulation Model

This dissertation requires validating the output of IES-VE with respect to the total electricity consumption of an office cubicle in the selected building. The design features of the office cubicle are inculcated in the base case model simulated in the software. This is the base model to be referred to when various parameters of louvers are tested for. Following are the details of the cubicle:

4.3.1 Design of Office Module

The head office of 'Global Group of Companies', situated on the third floor of the selected Al Mezan Building is selected for this dissertation. One of the cubicles with its window opening on south direction is simulated in this dissertation as a prototype module.

This office module is of the following dimensions: 4000mm Depth X 3000mm Width X 3000mm Height. The module is located in such a way that, the window of the module faces the south direction. The base case of this module is simulated without any louvers. Louvers with various parameters will be added and results will be compared to the base case. Figure 4.1 shows the layout of the module.

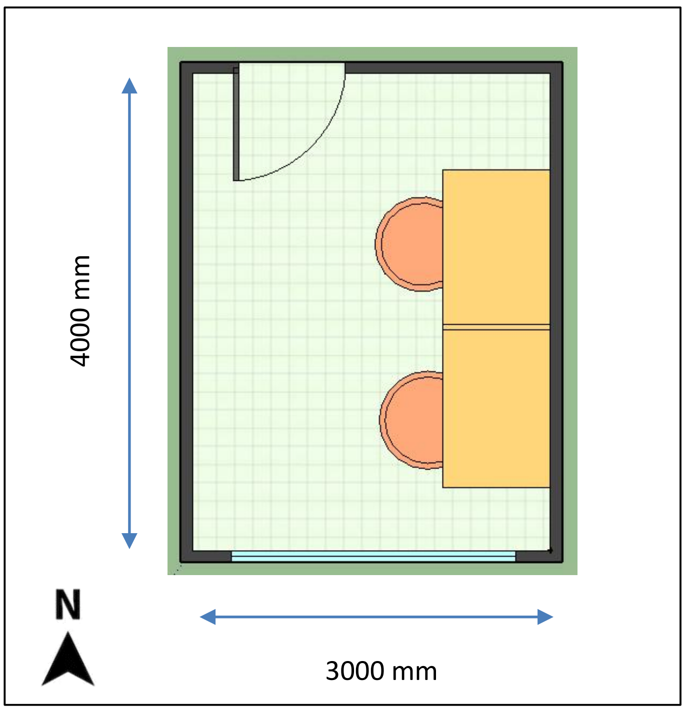

Figure 4.1 Layout of office module in Base case, by author.

4.3.2 Finishes of Office Module

The software of IES-VE facilitates applied materials to be incorporated in the model. The model simulation is exact when the actual material properties are considered in the simulation. Each of these materials has a unique conductivity and U-value. This affects the energy consumption of the simulated model. The office module is simulated using standard materials used in Dubai, for the fit out of a commercial building.

The tool of Building Template manager is used to create a construction template of the simulated model. In this template the specifications of materials used in the office are given with respect to sizes, conductivity and U-value. The construction materials used in the base case are worked on the basis of Dubai Green Building Code regulations for building elements of a construction. The figure 4.2 shows the Building Template manager window from the simulated IES model, highlighting the elements of the module and their U-Value.

☐	ID	Category	Description	Data source	U value (W/m²·K)	Thickness (mm)
☐	STD_DOOR	Door	2013 Door	Generic	2.1997	37.000
☐	STD_WAL1	External Wall	2013 External Wall	Generic	0.2885	295.000
☐	STD_EXTW	External Window	2013 External Window	Generic	1.9326	24.000
☐	STD_FLO1	Ground/Exposed Floor	2013 Exposed Floor	Generic	0.2179	368.200
☐	STD_ROOF	Roof	2013 Roof	Generic	0.1800	317.000

Figure 4.2 Building Template manager (IES-VE).

4.3.3 Constant Parameters of the Module

The office model is assumed to have certain fixed parameters. These parameters will remain constant for all the further simulations, so that effect of variable parameters can be properly analyzed. The model is a work space for two adults with Maximum Sensible Gain 90 Watt/ Person. The equipment in the module consists of two computer stations of 370 Watt each. The room temperature is controlled at 23 degree Celsius. The heating profile of the model is switched off continuously, since the office requires no heating. The cooling profile of the model is kept on continuously as per the working hours of the office. The HVAC profile is set to 0.25 Air Change per Hour. Artificial lighting is added to the model, in order to get a comprehensive picture of the energy use. 2 fluorescent lights of maximum sensible gain of 18.75 W/sqm are added to the model. The values of the set parameters are validated by comparison with similar studies conducted by Hammad and Abu-Hijleh (2010) for office building in Abu Dhabi.

4.3.4 Simulation Profiles

In IES-VE software, profiles can be created to give variation in schedules of time over a year. HVAC, lighting, equipment usage and occupancy of the people can be realistically set up using daily, weekly and annual profiles. APpro Project Profiles is the tool used to create these user profiles. Patterns of occupancy of the module are defined by the working pattern of the office. As per the common working practices in Dubai, the office is considered to be working during weekdays, from 9.00 am to 6.00 pm. This particular office also works on Saturday, hence the profile for Saturday is also set same as a weekday. Friday, being the weekend, the office is assumed to be closed.

Daily profile:

There are two types of daily profiles created. First is named as People HVAC Daily Profile. This is the main profile that considers the daily office timings of 9am to 6pm, during which the modulating value is 1 unit. From 6pm to next day 9am, the profile is switched off. Hence the value is 0 units. The use of HVAC, equipment and occupancy decides the structure of this profile during the whole day. Hence the simulation model will only validate using this information of daily profile. The fig. 4.3 shows the daily profile as per the input in IES-VE.

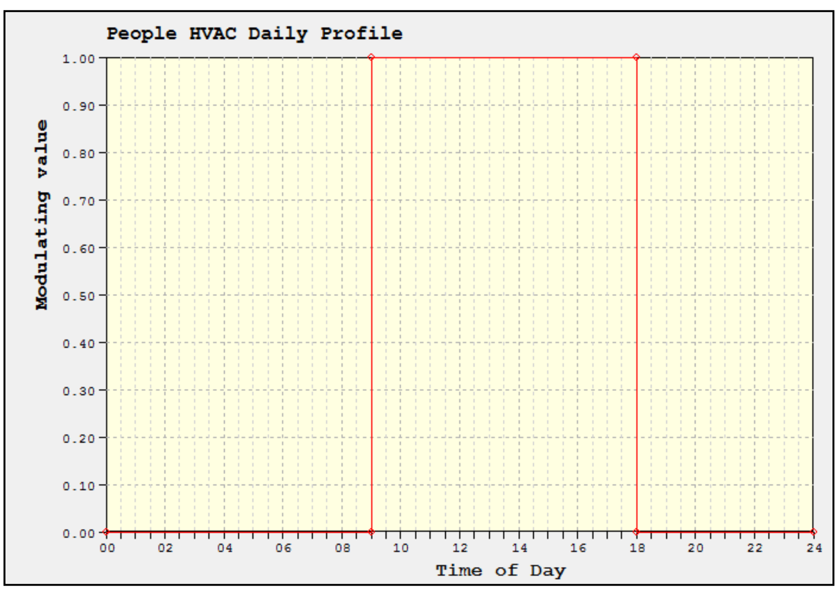

Figure 4.3 People HVAC Daily Profile for occupancy and HVAC, (IES-VE).

Secondly is the Daily lighting profile. This is the dimming profile which activates when the sensor captures that the lux levels in the room is less than 500 lux. If the luminance in the cabin is more than 500, it will dim the lights to 0.4 of its original lux levels. The formula for this fed in the IES-VE software as ramp (e1,0,1,500,0.4). Fig 4.4 shows the Daily Lighting Profile as set in IES-VE.

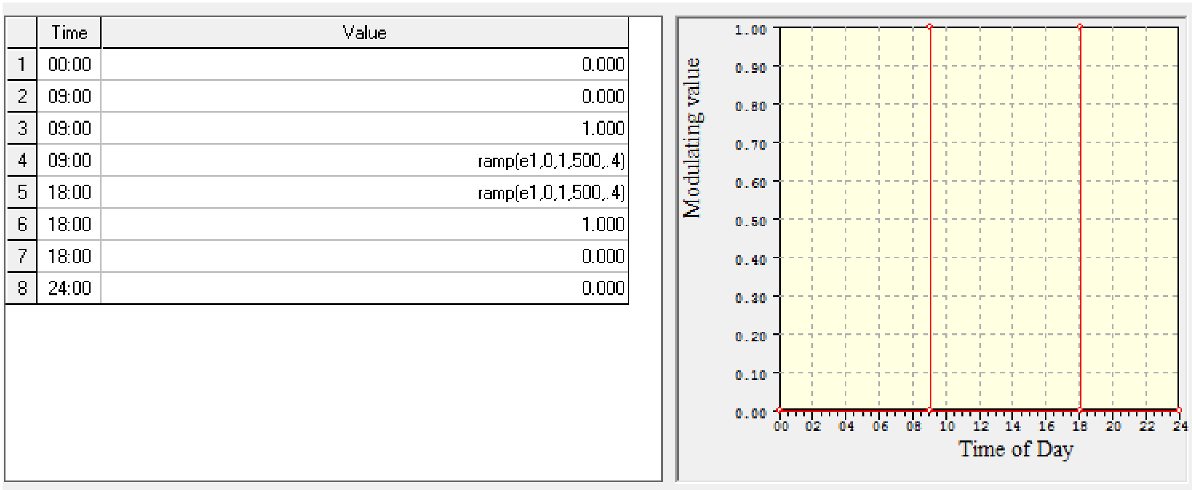

Figure 4.4 Daily lighting Profile for Lighting, (IES-VE).

Weekly profile:

The weekly profile incorporates the schedules of either of the activated daily profiles and creates another schedule for weekly pattern. The graph of weekly profile shows that on Friday the daily profile is deactivated. Saturday, being a working day for this particular office, the weekly profile is switched on. The fig. 4.5 shows the weekly profile as per the input in IES-VE.

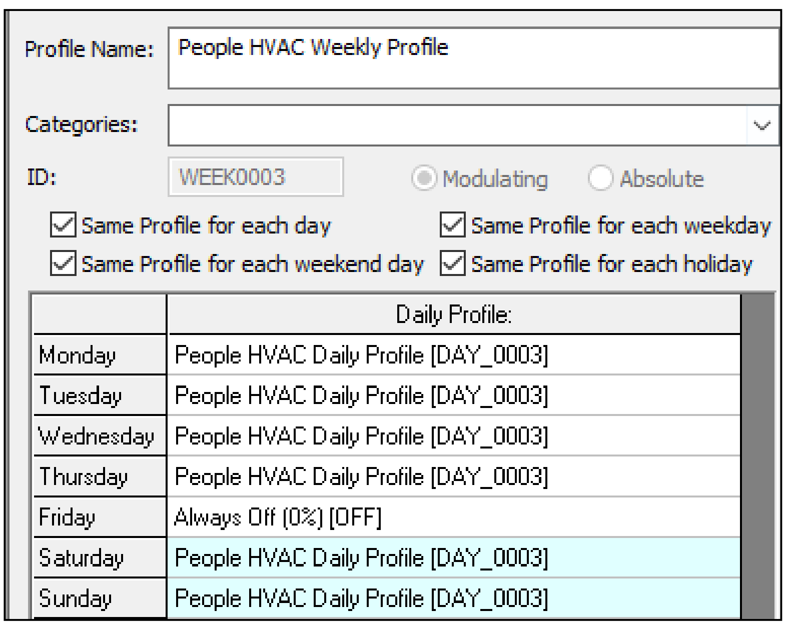

Figure 4.5 Weekly Profile for occupancy and HVAC, (IES-VE).

Annual Profile:

There is no major change in the annual schedule of the office working pattern. Hence there is no consideration for annual profile in the simulation model.

4.3.5 Weather Data

ApLocate is a database in IES-VE which consists of climatic data of a lot of cities in the world. This dissertation has used APLocate to obtain the weather data for Abu Dhabi, since weather file of Dubai is not available in the database. Hence Abu Dhabi weather file has been used as the nearest location available to where the site is located. The file of Abu Dhabi gives the current climatic conditions as following:

Hourly values of dry-bulb and wet-bulb temperature,

Direct normal and horizontal diffuse solar radiation

Solar altitude and azimuth

Wind speed and direction

Cloud cover

Atmospheric pressure

The co-ordinates of Dubai are 25.25° North Latitude and 55.33° East Longitude as shown in Fig. 4.6

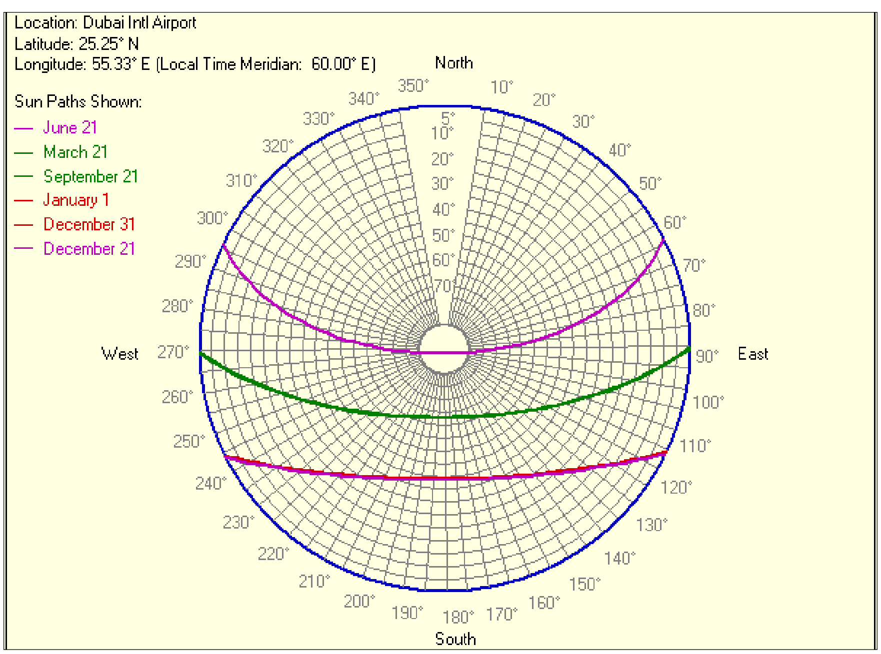

Figure 4.6 Sun path diagram for Dubai, (IES-VE).

IES VE database generates weather file for the specified location. The weather file in Figure 4.7 shows that July and August are the peak months of heat for UAE. The climate is extreme in hot and cold seasons. The temperature drops till 17 ° C in the month of January, while rises to an extreme of 45 ° C in the month of August.

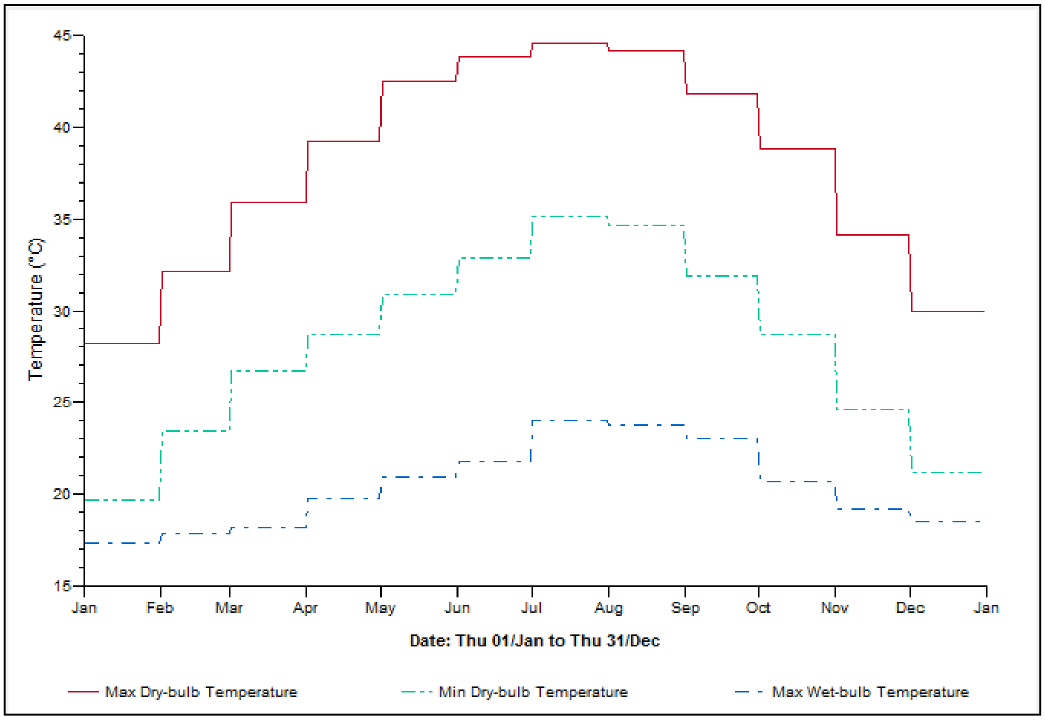

Figure 4.7 Annual weather data for Dubai, (IES-VE).

The figures 4.8 to 4.11 show the weather data of Dubai on annual as well as selected daily basis. The data shows that direct normal radiation is always on a higher side in UAE. The drop-in temperature in the month of January, does not affect the solar radiation. The solar radiation is always in the range of 600 to 800 w/sq.m. This states that the high solar radiation can be actively used for energy efficiency in UAE.

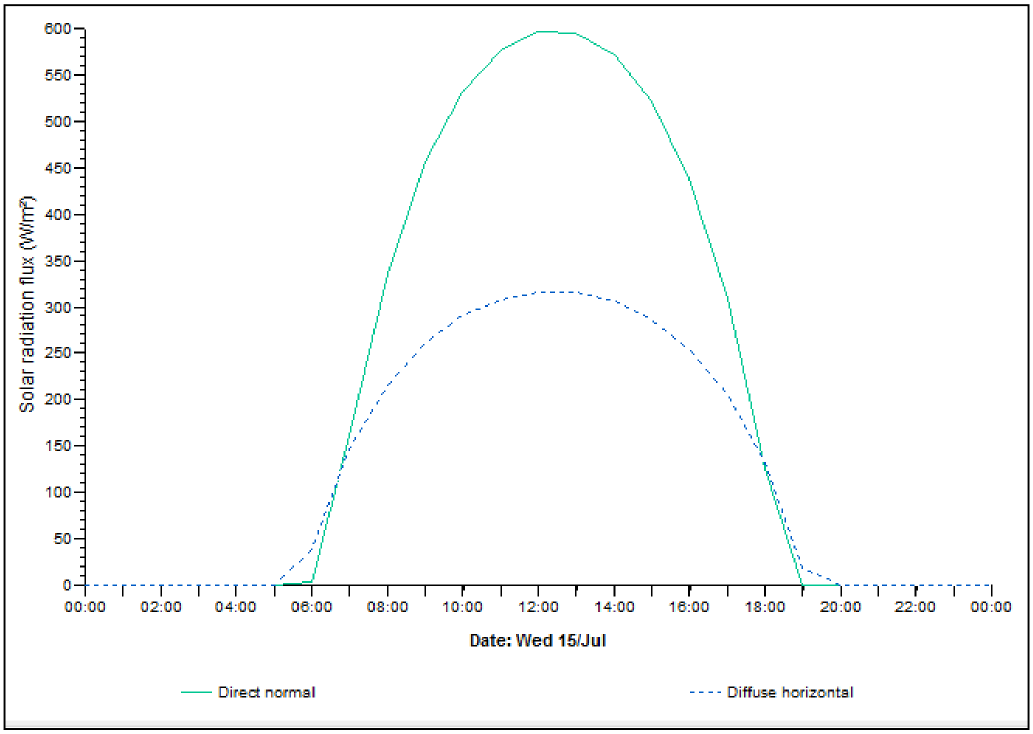

Figure 4.8 Weather data for Dubai on 15th July, (IES-VE).

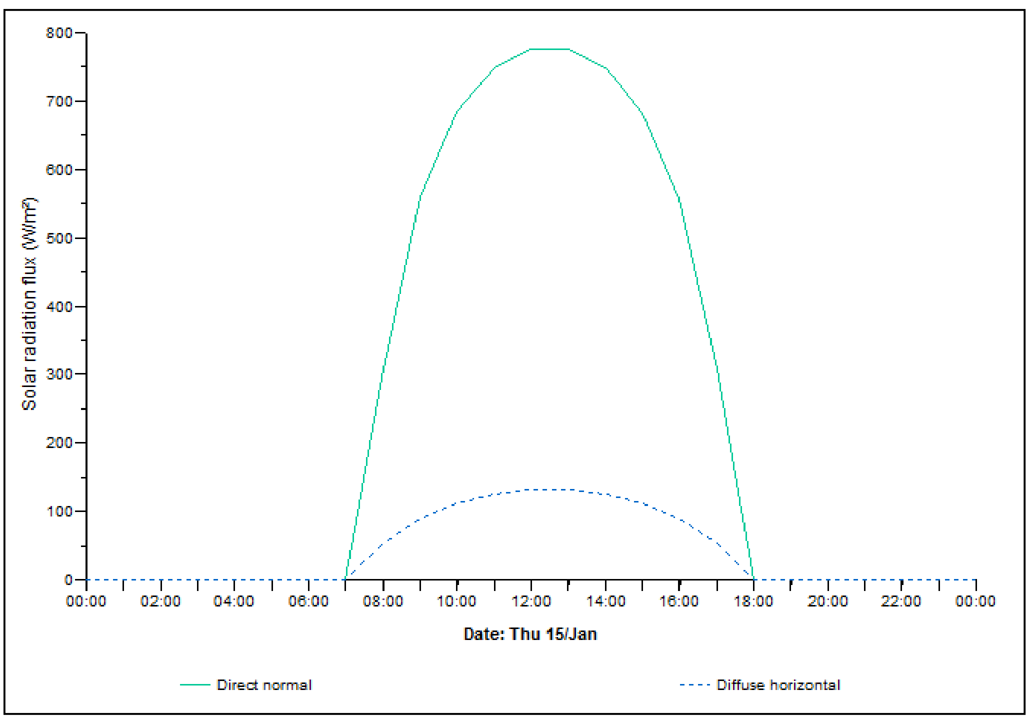

Figure 4.9 Weather data for Dubai on 15th January, (IES-VE).

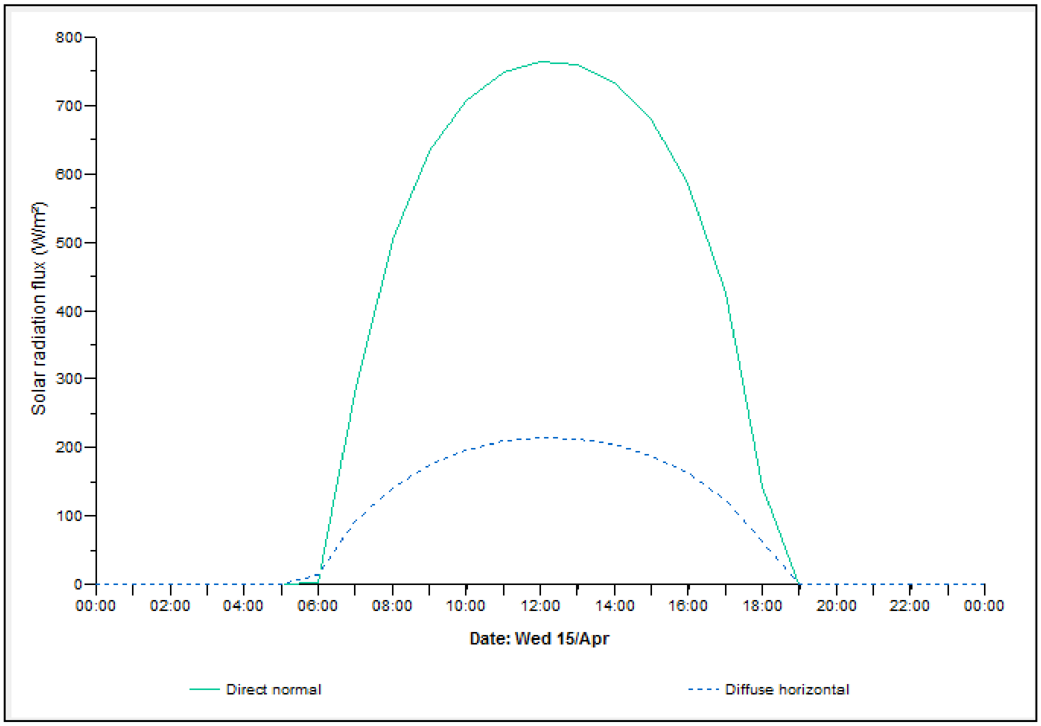

Figure 4.10 Weather data for Dubai on 15th April, (IES-VE).

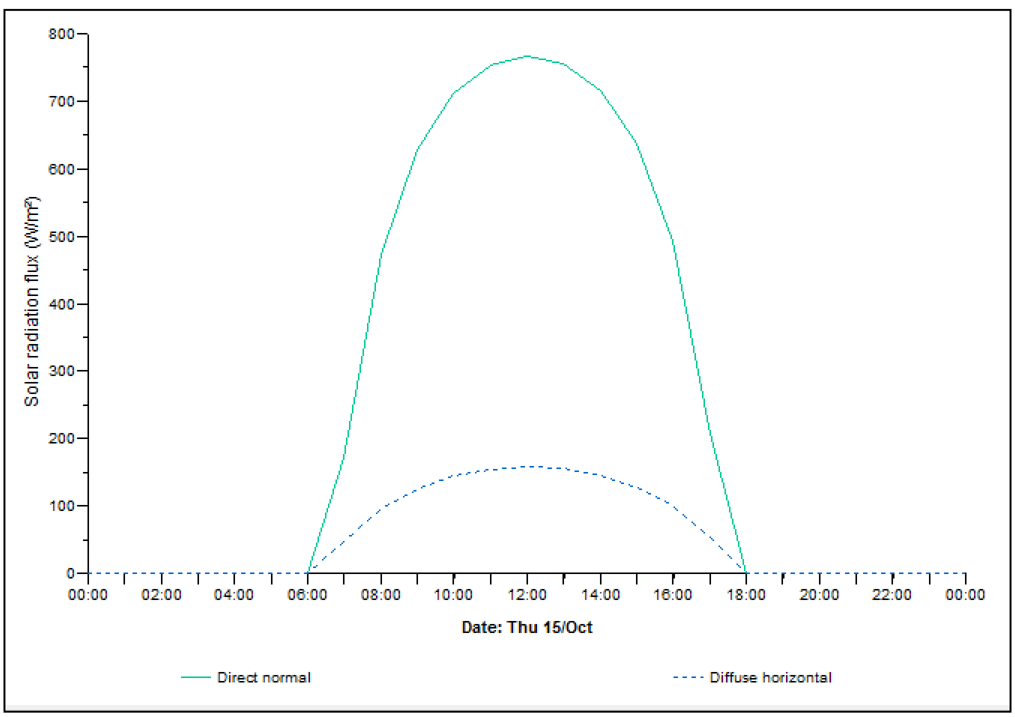

Figure 4.11 Weather data for Dubai on 15th October, (IES-VE).

4.4 Validation of Base Case:

The base case of the module is created as a basis for comparison. The base case model shows the cubicle with glazed façade to the south. It does not have any louvers or PVs built on it. This base case is simulated in IES-VE to understand the consumption of the model. The base case consumption is compared to actual consumption of the office through FEWA bills in Table 4.1. The actual bills are given in Appendix 1.

The electricity bills of the office show the consumption in kWh, which is taken as a basis of comparison. After collecting the data of one-year bills of the office, it is tabulated to get the annual consumption of the office. The cabin simulated occupies only one fourth area of the whole office. Hence in order to compare the results of both, the unit consumption of both is considered.

Area of office: 52 Sqm

Area of simulated model: 12 Sqm

Base Case	Simulated Consumption		Actual Consumption	
Date	Total electricity (kWh)	Unit Consumption (kWh/Sqm)	Total electricity (kWh)	Unit Consumption (kWh/Sqm)
Jan 01-31	289.3	24.11	1237	23.79
Feb 01-28	276.7	23.06	1440	27.69
Mar 01-31	296.5	24.71	1331	25.60
Apr 01-30	298.3	24.86	1405	27.02
May 01-31	316.6	26.38	1444	27.77
Jun 01-30	331.8	27.65	1377	26.48
Jul 01-31	357.6	29.80	1486	28.58
Aug 01-31	353.4	29.45	1443	27.75
Sep 01-30	356.6	29.72	1239	23.83
Oct 01-31	354.9	29.58	1525	29.33
Nov 01-30	339.9	28.33	1683	32.37
Dec 01-31	316.6	26.38	1603	30.83
Summed total	**3888.3**	**324.02**	**17213**	**331.02**

Table 4.1 Comparison of simulated to actual consumption (simulated in IES-VE, DEWA bills).

The annual unit electricity consumption (Simulated) is 324.02 kWh

The annual unit electricity consumption (Actual) is 331 kWh

Difference in annual consumption of simulation result and actual result is

(331 - 324.02) / 331 = 2.11 %

Hence, difference in simulation result and actual result is 2.11 %

The comparison of simulated energy consumption is similar to the actual consumption of the module by a variable allowance of less than 4 %. Hence the model simulated in base case is validated. This model can now be used as a basis for all the next set of simulations. The further cases of simulations will be carried out with comparative analysis to this validated base case model.

4.5 Boundary configuration of the model

In actual conditions of the office cabin, the south facing wall is majorly responsible for solar heat gain, whereas rest of the walls, ceiling and floor do not contribute to much heat gain. This is because the office cubicle is a part of a while building and heat transfer for internal building entities is very minimal.

For the purpose of simulation, the model is simulated as a stand-alone entity in IES-VE, in order to understand the effect of instantaneous solar value on the south façade. The boundary entities of the model such as other walls, ceiling and floor have been provided with additional insulation, so that the electricity consumption range matches that of a model simulated with adjacent cubicle scenario. Hence the condition of the cabin being a part of an office building is simulated in IES by the use of material properties given to boundary entities of the cubicle.

The results of base case were checked, and the month of July was found to be the peak contributor to energy consumption throughout the year. This is in lines with similar studies conducted by Al-Geresi (2011) and Hammad and Abu-Hijleh (2010) where July and August were found to be the highest energy consumption months. Hence this configuration holds true for the base case model. All further simulations are analyzed with respect to this base case and the dissertation focuses on the percentage decrease in energy consumption from the base case value.

4.6 Simulation Process

With respect to the base case, louvers are simulated at different conditions. Louvers are considered to be fixed on the south oriented glass façade of the office module. The fig 4.13 shows the image of the model from IES-VE. Louvers are fixed to the whole module width. The louvers are fixed at one end to the glazing façade. Distance between louvers is the center to center (CC) of louvers. Angle of the louver from the horizontal is considered the direction of measuring variation in angle. The parameters of angle, CC and width are also sketched in fig 4.12.

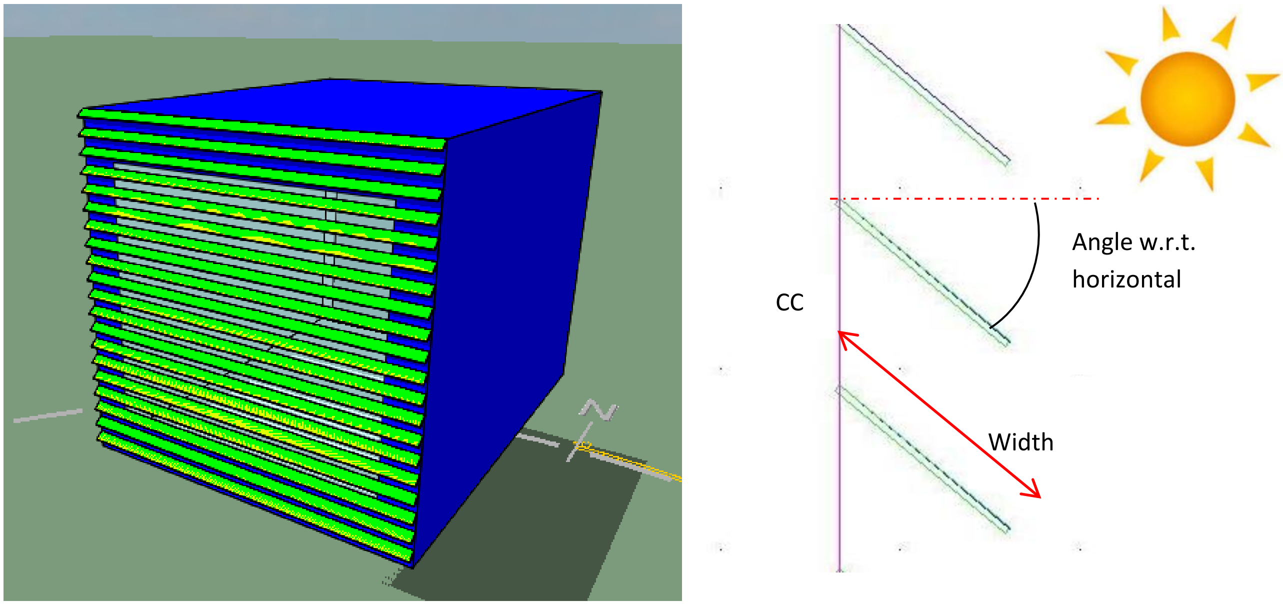

Figure 4.12 Model image from IES-VE (simulated in IES-VE).

The cabin is considered to be one module. Hence the effects of these results can be tested by multiplying the louver configuration to the whole building. This dissertation shows the effects of the selected louver configuration on the single module generated.

Size of the louvers is considered to be 3000mm L X 90mm W X 6mm H X 20 Nos of louvers. The center to center of louvers is considered to be 150mm and angle is fixed at 40 degrees. PV type on the louvers is considered to be thin film. These parameters are kept constant and each case is simulated with variation to a single category of these parameter. The simulation matrix used for this dissertation is tabulated in Table 4.2. This gives an overall understanding of all the variable and fixed parameters used in the simulation. A standard width (90mm), CC (150mm), angle (40 degrees) and PV type (thin film) is used for all the simulations. These standard configuration values are then varied in each case, to see the best-case scenario for each.

SIMULATION MATRIX: SELECTED PARAMETER FOR ALL CASES

	CASE	Case 1	Case 2	Case 3	Case 4
PARAMETER	VALUE	Variable Angle	Variable Width	Variable CC	Variable PV Type
LOUVER ANGLE	20 DEGREE				
	30 DEGREE				
	40 DEGREE				
	50 DEGREE				
	60 DEGREE				
LOUVER WIDTH	50 MM				
	90 MM				
	120 MM				
	150 MM				
	180 MM				
LOUVER C/C	80 MM				
	90 MM				
	120 MM				
	150 MM				
	180 MM				
PV CELL TYPE	MONOCRYSTALLINE				
	POLYCRYSTALLINE				
	THIN FILM				

LEGEND

SELECTED FIXED PARAMETER

SELECTED VARIABLE PARAMETER

Table 4.2 Simulation Matrix, by Author

The condition of louvers with integrated photovoltaic cells is also considered as a case for this dissertation. With the help of this, the amount of PV generated electricity can be studied for each case. This can give an idea about the value of energy efficiency and also can analyze if the installation of PV cells in louvers is financially viable option. The photovoltaic cell modules are considered to be the same width of each louver. Hence the variation in louver width will also affect the PV generated electricity. The type of PV cells will also be varied in the dissertation and effects will be studied on electricity generation. Orientation of PV cells is to the south, same direction as the louvers.

The condition of dimmer sensor being on or off is simulated for each simulation. To check the effect of dimmer sensor individually, the base case is also simulated with dimmer sensor condition on and off. This shows how much energy will be saved by addition of dimmer sensor, irrespective of addition of louvers or PV. Dimmer sensor is linked to the artificial lighting in the cubicle. When the lux level in the cubicle is more than 500, the dimmer sensor is activated and the lighting is reduced to 0.4 power of its original. The effect of dimmer sensor is studied on louvers with and without PV.

The table 4.3 shows format of tabulating the simulation results for louvers with and without PV, for dimmer sensor (DS) conditions on and off.

TABULATION OF SIMULATION RESULTS				
	Louvers without PV_DS-OFF	Louvers without PV_DS-ON	Louvers with PV_Ds-OFF	Louvers with PV_Ds-ON
VARIATION IN ANGLE				
VARIATION IN WIDTH				
VARIATION IN CC				
VARIATION IN PV TYPE				

Table 4.3 Tabulation format of results, by Author.

4.6.1 Simulation of Case 1:

In case 1, the louver angle is varied from 20 degree to 60 degree, calculated with respected to horizontal.

The standard configuration value of angle is 40 degree, but Case 1 simulates variable angle for the above-mentioned values. Angle of solar radiation determines the heat gain in the cabin. Hence different values of angles are being tested to see which the optimum value for least energy consumption is. The model is simulated for louvers with and without PV, with dimming sensor conditions to be on and off.

4.6.2 Simulation of Case 2:

In case 2, the louver width is varied as 50mm, 90mm, 120mm, 150mm and 180mm. The wider surface of the louvers creates more shade and reduces the heat gain in the cabin. But this condition also has a risk of over shading and the lux levels in the interiors might get affected. Hence it is important to test the efficient louver width, which can balance the energy consumption to shading factor.

The standard configuration value of width is 90mm, but Case 2 simulates variable width for the above-mentioned values. The model is simulated for louvers with and without PV, with dimming sensor conditions to be on and off.

4.6.3 Simulation of Case 3

In case 3, the louver center to center (CC) is varied as 80mm, 90mm, 120mm, 150mm and 180mm. The distance between center to center of louvers determines the quantity of louvers to be used in the model. Wider distance needs lesser number of louvers, which has an impact of energy and cost results. More the gap between two louvers, higher is the het gain in the interior. Lesser gap in center to center can affect the desirable lux levels for the office. Hence simulating various CC conditions is important in order to achieve a balanced value of optimum configuration.

The standard configuration value of CC is 150mm, but Case 3 simulates variable CC for the above-mentioned values. The model is simulated for louvers with and without PV, with dimming sensor conditions to be on and off.

4.6.4 Simulation of Case 4:

Case 4 shows simulation of different PV types. The composition of PV cells affects its efficiency. Hence mono crystalline and polycrystalline PV cells are also simulated along with standard configuration of thin film PV cells. The model is simulated for louvers with PV, with dimming sensor conditions to be on and off.

4.6.5 Simulation of Tracking Angle:

The sun azimuth angle and direct solar radiation differs from season to season. The heat gain on the south façade also differs throughout the day, as the sun path changes from east to west. Hence, a single configuration cannot be held true for different months and different time of the year and day respectively. In order to refine the efficiency of the louvers, a tracking angle configuration is proposed. This enables the louvers to change their angle throughout the day and for different months. Since IES-VE is unable to simulate the smart louver tracking angle, this is analyzed manually by the tracking angle matrix developed by the author. 21st of December, March, June and September are selected as four days, to cover the different seasons throughout the year. The angle of louvers is during the office hours is noted from 9:30 am to 5:30 pm. Out of the variation in angle from 20 degrees to 60 degrees, the most optimum angle is noted at each hour. The efficiency of the angle is based on lowest energy consumption at each hour.

5. Results and Discussion

5.1 Overview

This chapter gives a detailed discussion of the results of the simulation process explained. More than 72 conditions of the louvers were simulated in this dissertation and their results are given in this chapter. There is also a discussion as to why a particular condition of louvers may have performed better than another one. The general trend of the louvers in each case is highlighted, which might help in standardizing an optimum configuration. An efficient case scenario is generated with respect to sustainable and economic parameters.

5.2 Dimmer Sensor results on Base Case

In order to investigate the effect of dimmer sensors individually, the module is simulated with sensor conditions on and off. Table 5.1 shows electricity consumption by use of dimmer sensors.

Base Case	**Dimmer Sensor OFF**	**Dimmer Sensor ON**
Date	**Total electricity (MWh)**	**Total electricity (MWh)**
	Base Case_DSon.aps	Base Case_DSon.aps
Jan 01-31	0.3135	0.2684
Feb 01-28	0.2949	0.252
Mar 01-31	0.3042	0.2559
Apr 01-30	0.2871	0.2405
May 01-31	0.292	0.2455
Jun 01-30	0.2986	0.252
Jul 01-31	0.3191	0.2707
Aug 01-31	0.3165	0.2699
Sep 01-30	0.3285	0.2819
Oct 01-31	0.3433	0.2983
Nov 01-30	0.3451	0.3005
Dec 01-31	0.3357	0.2892
Summed total	3.7785	3.2249
Savings w.r.t. Base Case		**14.65%**

Table 5.1 Total electricity consumption results of Dimmer conditions, by Author.

The results in Table 5.1 show that linking dimmer sensor to artificial lighting, creates 14.65% savings in the total annual consumption, irrespective of any louver or PV condition. This shows that dimmer sensors are an efficient solution for energy savings and optimum energy usage, without much cost impact. On its own, a dimmer sensor can reduce the consumption of electricity required by a space. It does not need any changes in existing design and can be easily accommodated in the existing MEP services. The proposal of dimmer sensors creates a significant impact on energy savings as compared to the minimum investment cost required for it, compared to louvers and PV cells. Hence the condition of dimmer sensor is taken to be an important highlight of this dissertation, and all the further simulations are taken place with sensor on and off conditions.

5.3 Case 1 Simulation Results

In case 1 the louvers are oriented at different angles of the slats. The IES-VE simulation result shows the electricity consumption of different slat angles. Table 5.2 is a comprehensive chart showing total electricity consumption of louvers with and without PV and with dimmer sensor (DS) condition on and off.

VARIATION IN ANGLE: SUMMARY				
	Louvers without PV DS-OFF	Louvers without PV DS-ON	Louvers with PV Ds-OFF	Louvers with PV Ds-ON
20 Degrees	10.59%	24.66%	16.07%	30.14%
30 Degrees	11.56%	25.63%	17.40%	31.47%
40 Degrees	11.81%	25.89%	17.83%	31.90%
50 Degrees	11.86%	25.93%	17.91%	31.98%
60 Degrees	11.65%	25.72%	17.64%	31.71%

Table 5.2 Total electricity consumption results of Case 1, by Author.

Table 5.2 shows a summary of various angles simulated in Case 1. The individual result graphs of each angle degree can be found in Appendix 2. This gives the monthly breakup of each parameter for all the cases simulated in this dissertation, for PV cells and DS conditions.

The graph in Fig 5.1 shows the electricity consumption of different louver angles, as per results from IES- VE.

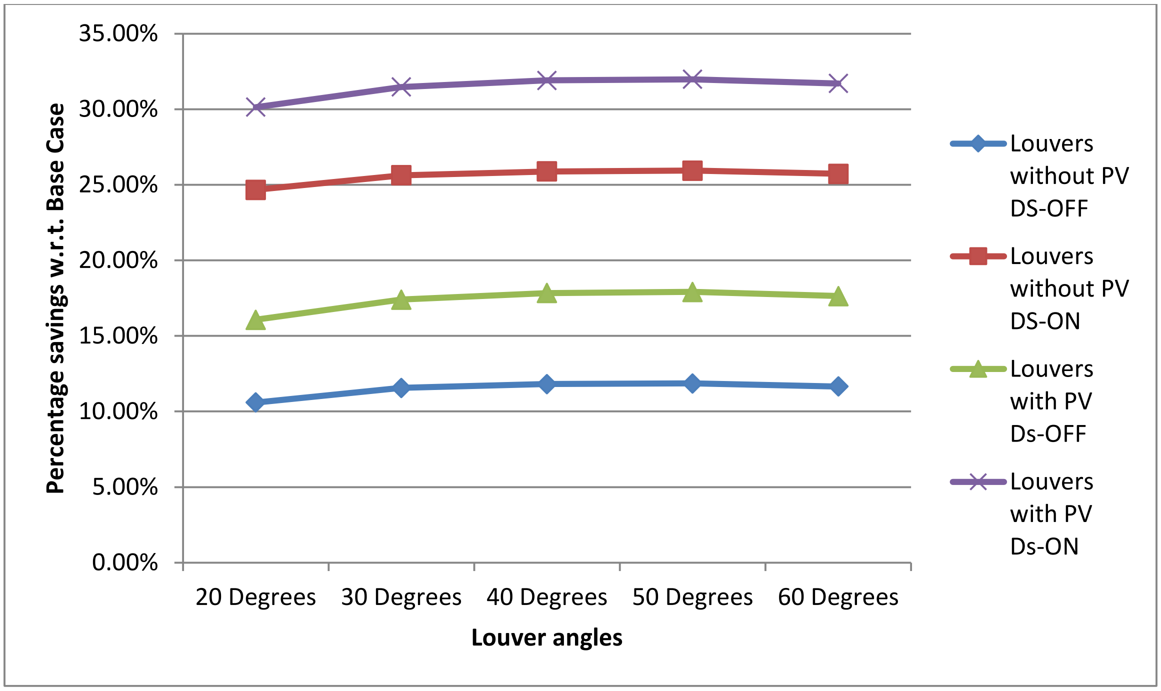

Figure 5.1 Comparison graph of results of Case 1, by Author.

The data tabulated from the simulation results shows that there is a steady increase in savings from 20 degrees angle to 50 degrees. At 50 degrees the savings is highest and then drops down at 60 degrees. The difference in increase of savings after 40 degrees is marginally very less. This is the general trend seen for louvers with and without PV, with both the dimmer conditions.

It can be said that for the location of Dubai and for south facing orientation, the louver condition of 40 degrees to 60 degrees plays an efficient role in minimizing the direct solar radiation. The angle of slats at 50 degrees is optimum for creating a shade for the office at this particular location. Hence 50-degree louver condition is taken to be the most efficient amongst all the other angles. Louvers without PV oriented at 50 degrees show 11.86% savings with dimmer condition off. The same louvers, with addition of PV show 17.91% savings, due to the electricity generated by the PV cells. This also shows that 50-degree angle is the most effective for electricity generation by PV, due to its directly perpendicular azimuth on the vertical south facing window.

The simulation results for two dimmer conditions show a good saving in energy due to dimmer sensor. For louvers fixed at 50 degrees without PV, the energy savings of 11.86% increased to 25.93% showing almost 14% increase in savings. For louvers with PV also, the result of 25.93% savings increased to 31.98% savings, with the addition of dimmer sensor. This shows that the artificial lighting can be switched off at certain times when the sensors are activated and it can contribute to almost 6 % of energy savings additional to the PV generated electricity savings.

Overall it can be seen that louvers with 50-degree angle show the maximum savings with respect to base case. Hence this louver condition is taken to be the most efficient in the case 1 simulation results.

5.4 Case 2 Simulation Results

In case 2 the louvers widths are changed to analyze the result on electricity consumption. This is tabulated for louvers with and without PV, with dimmer sensor condition on and off. Table. 5.3 is a comprehensive chart showing electricity consumption of louvers for the above-mentioned conditions and the graph is shown in Fig. 5.2.

VARIATION IN WIDTH: SUMMARY				
	Louvers without PV DS-OFF	Louvers without PV DS-ON	Louvers with PV Ds-OFF	Louvers with PV Ds-ON
50mm	7.62%	21.69%	11.35%	25.42%
90mm	11.81%	25.89%	17.83%	31.90%
120mm	13.50%	27.57%	20.15%	34.22%
150mm	13.80%	27.86%	20.89%	34.96%
180mm	13.90%	27.97%	21.40%	35.47%

Table 5.3 Total electricity consumption results of Case 2, by Author.

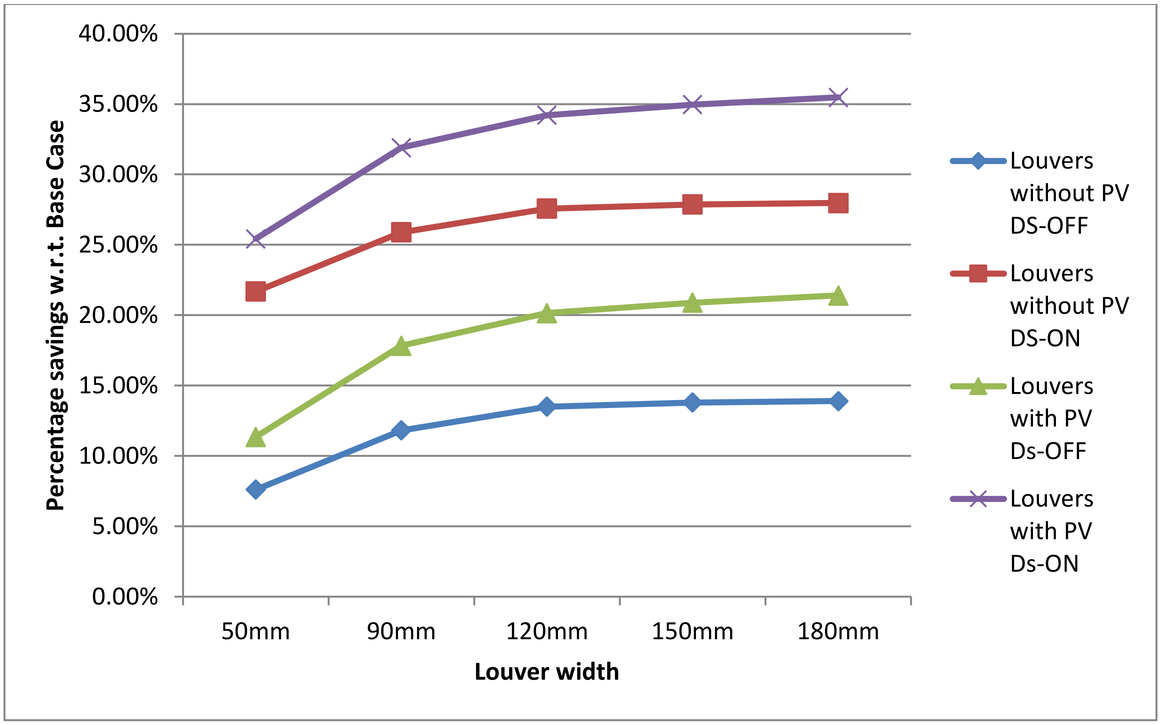

Figure 5.2 Comparison graph of results of Case 2, by Author.

The savings percentage graph shows that the width of the louver is directly proportional to the energy efficiency displayed by the cubicle. Wider the louver, more is the shading in the room, hence the electricity consumption due to load on HVAC is less.

For louvers without PV, the width corresponds to more shading factor in the office interiors. Hence increase in width, gives more savings with respect to base case of electricity consumption. The energy savings of 7.62% shown by louvers with 50mm width, increase along with the louver width. Louvers with 120mm, 150mm and 180mm show a minimal change in energy efficiency, with values of 13.5%, 13.8% and 13.9% respectively. This means that the louver efficiency remains more or less steady after the big leap of increase at 120mm.

For louvers with PV also, this trend is same. The increase in width, makes more surface area available to generate electricity and hence the energy performance increases.120mm louvers show considerable increase at 20.15% savings as compared to 90mm and 50mm louvers at 17.83% and 11.35%. After 120mm, the PV efficiency remains almost unchanged, with a very minor increase in savings within a range of additional 1%

Louvers with dimmer sensor condition on show a great progress in performance as compared to dimmer sensors being off. For 120mm louvers without PV, the energy savings of 13.5% increases to 27.57% just by the role of dimmer sensors. For louvers with PV also the dimmer sensor increases the energy efficiency to additional 14%, and the energy savings with respect to base case is 34.22%

For the conditions with and without PV, and on and off dimmer sensor, a common inclination of result is seen. The increase in louver width after 120mm does not show a marginally increased impact on the simulation results. This highlights the fact that the additional cost incurred to increase the PV width is not justified beyond 120mm. Hence 120mm is considered to be the most efficient parameter for various widths of the louvers.

5.5 Case 3 Simulation Results

Case 3 simulates different variations in louver center to center (CC). The results are simulated for louvers with and without PV, with dimmer sensor on and off. Table. 5.4 gives a summary of the simulation results and graph is shown in Fig. 5.3.

VARIATION IN CC: SUMMARY				
	Louvers without PV DS-OFF	Louvers without PV DS-ON	Louvers with PV Ds-OFF	Louvers with PV Ds-ON
80mm	13.89%	27.95%	20.79%	34.86%
90mm	13.81%	27.88%	20.85%	34.92%
120mm	13.33%	27.40%	20.01%	34.08%
150mm	11.81%	25.89%	17.83%	31.90%
180mm	10.47%	24.54%	15.91%	29.98%

Table 5.4 Total electricity consumption results of Case 3, by Author.

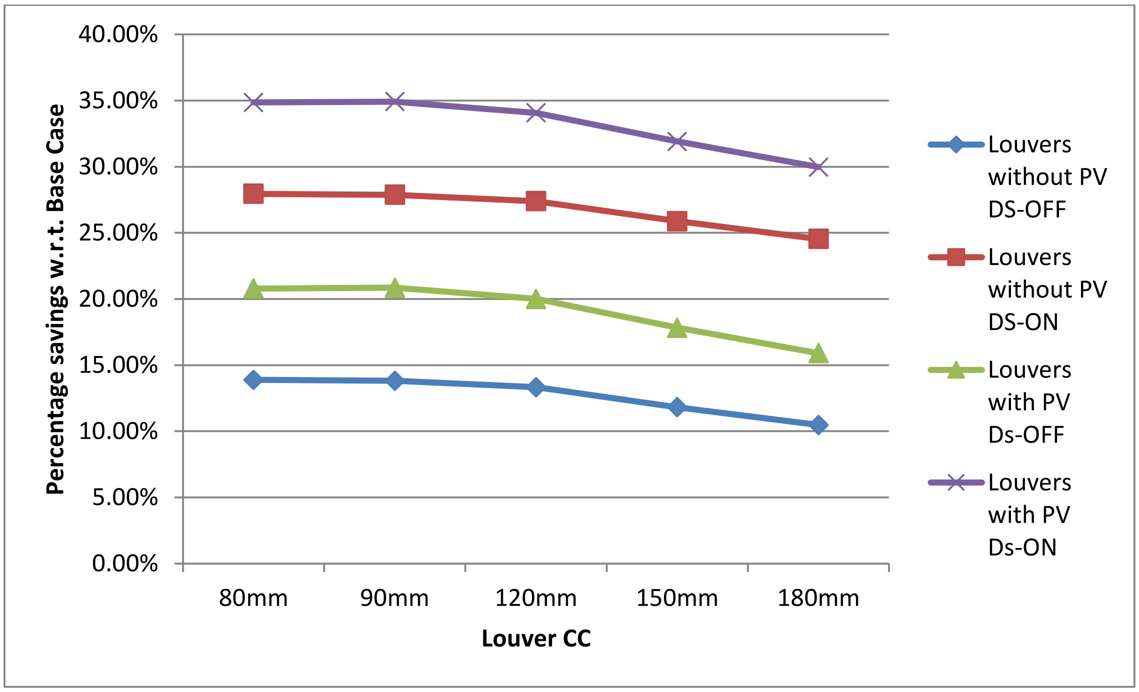

Figure 5.3 Comparison graph of results of Case 3, by Author.

Center to center of the louvers plays an important role in overall electricity consumption.

If the gap in between two louvers increases, the shading factor of the louvers decreases. Heat intake in the cubicle is more which creates additional energy expenditure on the HVAC. Hence the results of simulation of variation in CC show that increase in CC, decreases the energy savings with respect to base case.

The louver efficiency without PV decreases from 13.81% at 90mm, to 13.33% at 120mm and dips to 11.81% at 150mm center to center. At 180mm CC, the louvers CC is double of the width 90mm, and hence the energy efficiency dips the least to 10.47%. The louver with

90mm CC and without PV, shows 13.81% savings, and that with 80mm CC shows 13.89% savings. Since the louver width is 90mm, if the louvers are placed at 90mm CC, then it is possible to have a configuration where all the louvers close completely. Hence for the convenience of louver size corresponding to closed window configuration, the louver CC of 90mm is taken to be most efficient, even though 80mm shows a little more savings.

The louvers with PV, show maximum efficiency at 90mm because the angle of 50 degree and width 90mm works the best for center to center 90. There is no self-shading on the louvers since the louver width and louver CC is equal. The result of 20.85% CC for 90mm CC decreases to 20.01% for 120mm CC, 17.83% for 150mm CC and further to 15.91% for 180mm CC.

For louvers with dimmer sensor on, the results show a good acceleration from the condition with sensor off. Louvers without PV show a savings of 27.88% when the sensors are on, as compared to 13.81% when the sensors are off. For louvers with PV also, sensors play a vital role in saving 34.92% with respect to base case, rather than 20.85% without sensor. Hence it can be said that sensor linked to artificial lights can increase the energy efficiency by 6% and 14% for louvers without and with PV respectively.

The general movement of energy savings with respect to change in center to center, shows that 90mm CC works the best for the standard configuration. Closer is the center to center of the louvers, more will be the quantity of louvers required. The configuration of 90mm CC louvers requires 33 louvers, while 120mm and 150mm require only 25 numbers and 20 numbers of louvers respectively. Hence, economically viable option would be the one with minimum number of louvers, so that the cost of the proposal decreases. But, the energy savings tabulated from the simulations highlight the fact that, with dimmer sensor on, the savings decrease by almost 2 to 3 %, if the CC is increased. Hence there needs to be a balance in the CC configuration and cost analysis.

It can thus be stated that 90mm CC of louvers is seen as the most effective configuration for the above simulated results. This also considers the fact that lover width of 90mm gives an option of closing completely if the CC is set to 90mm. Hence this option is chosen to be most proficient from execution and energy efficiency point of view.

5.6 Case 4 Simulation Results

This case shows results of variation in PV cell types used for louvers with PV condition. The previous chapter explains the fixed and variable parameters of the louvers in this condition. The PV cell types of polycrystalline, mono crystalline and thin film are simulated in each of the fixed parameter conditions, to understand its effect on energy generation. Since the louvers without PV, do not qualify for this case, the results are only tabulated for louvers with PV, with dimmer sensor on and off.

Table. 5.5 shows the results of total electricity consumption simulated in case 4 and the graph of results is shown in Fig. 5.4.

VARIATION IN PV TYPES: SUMMARY		
	Louvers with PV_Ds-OFF	Louvers with PV_Ds-ON
MonoCrystalline	22.69%	36.76%
Polycrystalline	21.02%	35.09%
Thin Film	17.83%	31.90%

Table 5.5 Total electricity consumption results of Case 4, by Author.

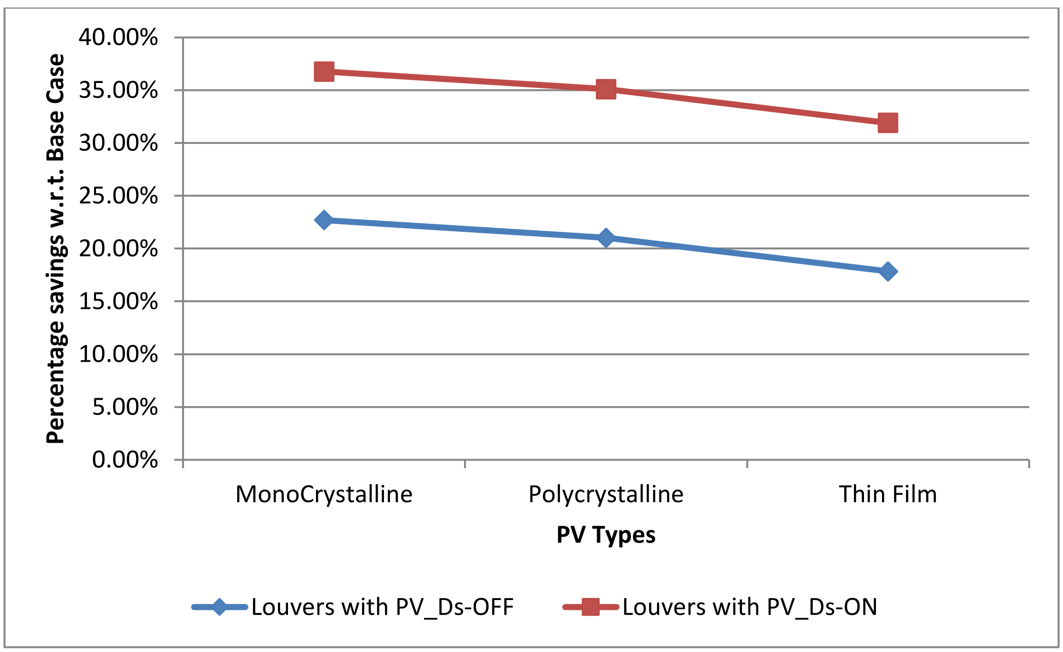

Figure 5.4 Comparison graph of results of Case 4, by Author.

For louvers with dimmer sensor off, mono crystalline PV cells show a savings of 22.69%, followed by polycrystalline cells at 21.02%. The thin film PV cells show the least savings of 17.83% amongst the three. For condition with dimmer sensor on, there is seen to be a great leap in savings. Mono crystalline cells perform the highest at 36.76% savings, followed by polycrystalline at 35.09% and then thin film at 31.90%.

Mono crystalline cells are produced from the highest grade of silicon. Even at low light conditions, these cells perform better than the thin film or poly crystalline options. However, the price range of mono crystalline is also more than the rest two options. From the economic point of view, it can be stated that poly crystalline cells is a better option, since the difference in energy savings in both is just around 1%. This does not justify the additional cost that has to be incurred in order to install mono crystalline cells.

Since the analysis in Case 4 is emphasized on energy efficiency options, it can be noted that mono crystalline PV cells are the most effective option for energy generation, giving a commendable result of 36.76% savings with respect to the base case.

5.7 Co-relation between louver width and louver center to center.

The simulation process for all the four cases have been well established in the above discussion. It is important to analyze the behavior of the configurations, with respect to the fixed parameters. The standard configuration for all cases are fixed at 40 degree angle, 90mm louver width, 150 mm CC and thin film type of PV cells. These configurations are constant in each case, with only change in the particular case variable. This gives a general uniformity in establishing the results, because all the simulations are analyzed on the basis of equal standards of louver configuration.

It is interesting to see that louver CC for 90mm width performed the best, whereas 120 and 150mm width were the most effecting for 150mm CC. This draws our attention to the possibility that there might be a co relation between louver CC and louver width parameters. Hence, this possibility is explored more in this discussion.

If the CC and width of the louvers is kept in the same range, there is a possibility that the energy efficiency increases. This can be because the louvers have minimum self-shading, due to CC configuration same as width. For south oriented window condition in this particular location, the amount of heat and light entering the cabin is optimized to least energy expenditure if the louver width and CC are balanced. In order to establish this co-relation, two comparative cases are simulated as follows:

Louver width and CC: 90mm

Louver width and CC: 150mm

The results of these two cases are simulated in table of Table. 5.6, to see the effect on energy consumption

COMPARISON BETWEEN EQUAL WIDTH AND CC: 90MM AND 150MM				
	Louvers without PV DS-OFF	Louvers without PV DS-ON	Louvers with PV Ds-OFF	Louvers with PV Ds-ON
90mm Width and CC	13.81%	27.88%	20.85%	34.92%
150mm Width and CC	13.79%	27.86%	20.82%	34.89%

Table 5.6 Comparison graph of equal width and CC: 90mm and 120mm, by Author.

The results of the above simulations show that energy savings in both the cases are almost similar. If louver width and louver CC is kept same for horizontal configuration of louvers, then the energy efficiency of the module increases. There is also an added benefit of closing the louvers completely, so that no heat gain is possible for times when the office is closed. The gap between the louvers can exactly fit the louver width, hence this configuration is also easy to manufacture and install. Both the conditions of 90mm and 150mm louver width and CC, show almost equal performance. Hence it is important to study the cost impact of both these conditions, using a simple payback method.

The cost of aluminum louvers is taken from quotation attached in Appendix 3. The value of electricity in UAE is calculated as a sum of electricity tariff plus cost of fuel surcharge as per bill details attached in Appendix 1. Hence the value of electricity is considered as 0.3 AED.

The economic impact of louvers is largely based on the total area. Hence the square meter rate of louver is used for payback period calculation. The cost analysis is performed for louvers without PV, and dimmer sensor ON. Table 5.7 shows the steps for the same:

Condition A 90mm Width and 90mm CC	Condition B 150mm Width and 150mm CC
The cost of aluminum louvers with 90mm W is 350 AED/ Sqm with installation charges included. The size of the louvers = 3000mm L X 90mm W X 33 nos Total area covered by the louvers is = 3 * 0.09 * 33 =8.91 Sqm The cost of louvers (with installation) = 350* 8.91= 3118.5 AED Annual electricity saved as compared to base case = 3.8883 - 2.8042 = 1.0841 MWh = 1084.1 kWh Value of electricity per kWh = 0.3 AED Annual value of saved electricity= 1084.1* 0.3 = 325.23 AED Simple payback period= Total cost / Annual saving in electricity = 3118.5 / 325.23= **10 years**	The cost of aluminum louvers with 150mm W is 410 AED/ Sqm with installation charges included. The size of the louvers = 3000mm L X 150mm W X 20 nos Total area covered by the louvers is = 3 * 0.15 * 20 = 9 Sqm The cost of louvers (with installation) = 410* 9 = 3690 AED Annual electricity saved as compared to base case = 3.8883 - 2.8050 = 1.0833 MWh = 1083.3 kWh Value of electricity per kWh = 0.3 AED Annual value of saved electricity= 1083.3* 0.3 = 324.99 AED Simple payback period= Total cost / Annual saving in electricity = 3690/ 324.99 = **12 years**

Table 5.7 Steps for Simple Payback, by Author

From the above calculations, it is clear that louver with 90mm Width and CC gives a payback period of 10 years, whereas the louvers with 150mm Width and CC gives a payback period of 12 years. In spite of louver quantity being less in 150mm CC, the area of the louver width is more, and hence there is not much change in total square meter coverage of louvers. On the contrary, manufacturing of wider louvers, has more cost impact, and hence the cost per sqm for 90mm CC is more efficient.

The key findings of the cost analysis highlight that 90mm width and CC louver is more efficient than the 150mm width and CC. Hence 90mm louver case will be considered for calculating the Economic Case

5.8 Tracking Angle Simulation Results

Fixed louvers and dynamic louvers are the two types in which louvers can be broadly classified. The results of all the simulations were on the basis of a fixed louver configuration. This means that the louver angle is fixed at the same degree for all the hours throughout the day, and all the seasons throughout the year. Dynamic louver condition gives the accessibility to change the louver angle at various hours, as the sun movement takes place from east to west. Since IES-VE does not simulate intelligent louvers, the dynamic condition is simulated manually. The louver angles from 20 degree to 60 degree are tabulated for each hour of the office working timing. The graph in Table 5.8 shows a matrix of simulation results of tracking angles.

		TIME									
		9:30 AM	10:30 AM	11:30 AM	12:30 PM	1:30 PM	2:30 PM	3:30 PM	4:30 PM	5:30 PM	TOTAL
	TRACKING ANGLE										
21ST DEC	20 Degrees	0.736	0.7925	0.8304	0.8525	0.8619	0.8595	0.845	0.8224	0.8703	7.4705
	30 Degrees	0.718	0.7795	0.8176	0.8395	0.849	0.8473	0.8339	0.8127	0.8623	7.3598
	40 Degrees	0.7109	0.7735	0.8112	0.8328	0.8422	0.8409	0.8282	0.8081	0.8591	7.3069
	50 Degrees	0.7078	0.7709	0.8086	0.8302	0.8396	0.8382	0.8256	0.8058	0.8575	7.2842
	60 Degrees	0.7082	0.7711	0.809	0.8309	0.8403	0.8385	0.8256	0.8056	0.8575	7.2867
21ST MAR	20 Degrees	0.8076	0.8531	0.8886	0.9089	0.9217	0.9208	0.8991	0.8785	0.8583	7.9366
	30 Degrees	0.7899	0.8432	0.8808	0.9019	0.9148	0.9137	0.8914	0.8703	0.85	7.856
	40 Degrees	0.7892	0.8431	0.881	0.9021	0.9151	0.9139	0.8913	0.8699	0.8494	7.855
	50 Degrees	0.7888	0.843	0.881	0.9022	0.9152	0.914	0.8912	0.8696	0.849	7.854
	60 Degrees	0.7887	0.843	0.8811	0.9023	0.9153	0.9141	0.8912	0.8696	0.849	7.8543
21ST JUN	20 Degrees	1.5808	1.3279	1.2828	1.2508	1.2339	1.2157	1.1896	1.1609	1.1339	11.3763
	30 Degrees	1.5602	1.3159	1.2733	1.2422	1.2254	1.2071	1.1807	1.1519	1.1248	11.2815
	40 Degrees	1.5585	1.3152	1.2731	1.242	1.2252	1.2068	1.1801	1.151	1.1239	11.2758
	50 Degrees	1.5574	1.3147	1.273	1.2419	1.2251	1.2066	1.1798	1.1505	1.1233	11.2723
	60 Degrees	1.5877	1.3293	1.268	1.2284	1.2041	1.1865	1.1691	1.1476	1.1239	11.2446
21ST SEP	20 Degrees	1.3828	1.1969	1.1676	1.1573	1.1499	1.1349	1.109	1.0804	1.0527	10.4315
	30 Degrees	1.3673	1.1878	1.1603	1.1511	1.1439	1.1287	1.1025	1.0737	1.0462	10.3615
	40 Degrees	1.3657	1.1869	1.1599	1.1509	1.1438	1.1283	1.1018	1.0728	1.0454	10.3555
	50 Degrees	1.3648	1.1864	1.1596	1.1508	1.1436	1.1281	1.1014	1.0722	1.0448	10.3517
	60 Degrees	1.3644	1.1862	1.1595	1.1507	1.1436	1.128	1.1013	1.072	1.0446	10.3503

Table 5.8 Tracking Angle Result Matrix, by Author.

The tracking angle is simulated for dimmer sensor condition on, since it is established from the results that sensor on condition helps in considerably increasing the energy savings. The results on 21st December and 21st September show that 50 degree angle works as the most effective throughout the day. From 4:30 pm to 5:30 pm, the angle of 60 degree works better in December, but the reduction in energy consumption is only 0.0002 MWh, which is very minimal.

For 21st March, there is a movement of energy consumption going up and down with the change in louver angle. From 9:30 am to 10:30 am the angle of 60 degree works the best, showing least energy consumption. From 11:30 am to 2:30pm the angle of 30 degree gives the best output of energy savings. From 3:30pm to 5:30 pm, again the optimum angle is seen to be 50 degrees or 60 degrees. This shows that if the louver angle is changed for 3 hours in the noon, there is a chance of more energy savings. However the result difference in this case is very less.

For 21st June also louver angle of 60 degrees is seen to be the most efficient, with a slight change at 9:30 am to 10:30 am and again at 5:30 pm. Changing the angle to 50 degree at these timings, can help in saving energy, but the difference in result is quite negligible.

The graph also gives a total energy consumption of the day to check which the optimum angle is. Overall it can be said, that changing the louver angles at different hours and different months, do not show a considerable effect on the energy savings, as compared to the cost incurred. Manually or automatically changing the louver angles, needs an investment in terms of money, technology and manpower. This cost is not justified by the very minimal change seen in the results. Hence it can be said that fixed louvers show a more efficient output, when compared to dynamic louvers, when the economic implications are weighed against energy savings.

5.9 Efficient Case and Economic Case

The best case cannot be decided over just one parameter of either energy efficiency or cost implication. The energy efficient case will have its cost implication. While the cost-efficient case will have lesser energy efficiency. Hence both these cases are studied with respect to simple payback period. Since PV type makes a huge impact in both these cases, louvers with PV are taken for the comparison. Dimmer sensor condition is kept ON for the simulation.

The efficient case is formulated using the most energy effective parameters simulated in each case. In Case 1, 50-degree angle is highlighted to be most effective. After co- relating the results of Case 2 and 3, the louver width of 90mm and louver CC of 90mm is considered to be most energy efficient. Mono crystalline PV type cells are considered as the most effective. All these parameters are simulated together, to get the results of efficient case.

SUMMARY: EFFICIENT CASE			
	Base Case	Louvers without PV_Ds-ON	Louvers with PV_Ds-ON
Total Consumption(MWh)	3.8883	2.8016	2.317
Savings w.r.t. Base Case		28%	40%

Table 5.9 Efficient Case results, by Author.

Economic Case is formulated using the most optimum option giving least payback period. In economic case 40 degree angle is used. After co- relating the results of Case 2 and 3, the louver width of 90mm and louver CC of 90mm is taken to be most cost effective with 10 years payback. Same configuration is used, with addition of PV cells. For economic case, thin film type of PV are used, since they have the least capital investment. The cost of supply and installation of louvers with mono crystalline PV cells and thin film PV cells is taken from quotation attached in Appendix 3. The value of electricity in UAE is calculated as a sum of electricity tariff plus cost of fuel surcharge as per bill details attached in Appendix 1. Hence the value of electricity is considered as 0.3 AED.

<u>Efficient Case</u>	<u>Economic Case</u>
Louver angle: 50 degrees Louver width: 90mm Louver CC: 90mm PV type: Mono crystalline The cost of 90mm W aluminum louvers with Mono crystalline PV cells is 950 AED/ Sqm with installation charges included. The size of the louvers = 3000mm L X 90mm W X 33 nos Total area covered by the louvers is = 3 * 0.09 * 33 =8.91 Sqm The cost of louvers (with installation) = 950* 8.91 = 8464.5 AED Annual electricity saved as compared to base case = 3.8883 - 2.317 = 1.5713 MWh = 1571.3 kWh Value of electricity per kWh = 0.3 AED Annual value of saved electricity= 1571.3* 0.3 = 471.39 AED Simple payback period= Total cost / Annual saving in electricity = 8464.5 / 471.39 = **18 years**	Louver angle: 40 degrees Louver width: 90mm Louver CC: 90mm PV type: Thin Film The cost of 90mm W aluminum louvers with Mono crystalline PV cells is 550 AED/ Sqm with installation charges included. The size of the louvers = 3000mm L X 90mm W X 33 nos Total area covered by the louvers is = 3 * 0.09 * 33 =8.91 Sqm The cost of louvers (with installation) = 550* 8.91= 4900.5 AED Annual electricity saved as compared to base case = 3.8883 - 2.5304 = 1.3579 MWh = 1357.9 kWh Value of electricity per kWh = 0.3 AED Annual value of saved electricity= 1357.9* 0.3 = 407.37 AED Simple payback period= Total cost / Annual saving in electricity = 4900.5 / 407.37 = **12 years**

Table 5.10 Efficient Case and Economic case: Payback period comparison, by Author.

The energy efficient case gives a payback period of 18 years, whereas the economic case, gives a payback period of 12 years. Since the cost of electricity in this location is very minimal, the payback period is of a higher value. The energy generated cannot sold back to the grid at a higher value, and hence there is no major difference in the savings commercially.

The result summary of all the simulations is tabulated in Table 5.11.

RESULT SUMMARY					
		Louvers without PV DS-OFF	Louvers without PV DS-ON	Louvers with PV Ds-OFF	Louvers with PV Ds-ON
VARIATION IN ANGLE	20 Degrees	10.59%	24.66%	16.07%	30.14%
	30 Degrees	11.56%	25.63%	17.40%	31.47%
	40 Degrees	11.81%	25.89%	17.83%	31.90%
	50 Degrees	11.86%	25.93%	17.91%	31.98%
	60 Degrees	11.65%	25.72%	17.64%	31.71%
VARIATION IN WIDTH	50mm	7.62%	21.69%	11.35%	25.42%
	90mm	11.81%	25.89%	17.83%	31.90%
	120mm	13.50%	27.57%	20.15%	34.22%
	150mm	13.80%	27.86%	20.89%	34.96%
	180mm	13.90%	27.97%	21.40%	35.47%
	210mm	13.93%	28.00%	21.67%	35.74%
VARIATION IN CC	80mm	13.89%	27.95%	20.79%	34.86%
	90mm	13.81%	27.88%	20.85%	34.92%
	120mm	13.33%	27.40%	20.01%	34.08%
	150mm	11.81%	25.89%	17.83%	31.90%
	180mm	10.47%	24.54%	15.91%	29.98%
VARIATION IN PV TYPE	MonoCrystalline	NIL	NIL	22.69%	36.76%
	Polycrystalline	NIL	NIL	21.02%	35.09%
	Thin Film	NIL	NIL	17.83%	31.90%

Table 5.11 Overall Results summary, by Author.

6. Conclusion and Recommendations

6.1 Overview

Reduced energy consumption is a vital factor towards sustainability and energy performance of a building. The selected office building in Dubai, has a glass façade on the south orientation. The glass façade leads to more heat absorption in the office interiors. This creates a load on existing HVAC system. Usage of more AC for cooling leads to hike in the electricity bill of the office. This scenario was studied in detail and the need of design elements for reduced energy consumption was generated.

The literature study describes in detail the functionality of louvers and shading devices being used for enhanced building performance. Various projects which used similar concepts, are studied and the pros and cons of each design proposal are noted down. By the use of IES-VE software, a simulation model of the office cabin is created. This model is validated using the electricity bills of the office.

The dissertation evaluates various parameters of horizontal louvers for the simulated model. Results in electricity consumption by changing values of each parameter are tabulated. The graphs of louvers with and without PV, and with dimmer sensor on and off are compared. After simulating the model in four cases, the most efficient result of each parameter is compiled together to formulate an efficient case.

This chapter gives a summary of the overall results achieved in the dissertation. It also highlights the key areas of work, which can be produced in the future on the same lines of this dissertation.

6.2 Conclusion

The simulated model of office cubicle is used to carry out different scenarios of louver conditions. The parameters of the louvers are varied with respect to angle orientation, louver width, louver CC and PV cell type. The result of change in each parameter is tabulated as a specific case scenario. More than 72 louver conditions are simulated including louvers with and without PV cells, and dimmer sensor condition as on or off.

The base case is simulated with and without dimmer sensor to highlight the effect of artificial lighting linked to sensor. The base case, without any PV or louvers shows 15% energy savings. This shows that execution of dimmer sensor for the cabin, can give optimum result at the least economic investment. This is taken as a basic proposal for energy savings solution. It is the most effective design proposal, and can be executed in any existing building fabric. The time, cost and efficiency impact of dimmer sensors is considerably high as compared to louvers and PV cells. Hence the cases with dimmer sensor on are taken as optimum cases for further discussion.

The next stage of design proposal is deployment of horizontal louvers. The investment in this proposal is slightly more, and the results are simulated with various parameters. The simulation results show that 50 degree angle is the most efficient throughout the year. Louvers without PV show energy savings of 24 to 25% than base case. Louvers with PV give a saving in the range of 30 to 31 %

The tracking angle simulation gives a proposal of changing the angle of louvers throughout the day and year, to simulate dynamic louvers. The results of tracking angle are very less in compared to other solutions and results seen in louvered options. The results do not show major change, except for the month of March. Hence the use of louvers fixed at 50 degrees is a more economically viable option, since installation and maintenance of a yearly and daily tracking angle system is a huge investment.

Case 2 shows that louvers without PV show energy savings in the range of 7 to 14% with change in width of the louvers. Louvers with PV show savings in the range of 25 to 35%. Similarly the louvers without PV give savings of 24 to 27% when the center to center of louvers is modified. Louvers with PV give energy savings of 30 to 34 % with change in louver CC. The comparative results of Case 2 and Case 3, brings to light the key finding that when the louver width and CC is kept constant, the energy efficiency increases. After calculating the simple payback period, it can be highlighted that 90mm width and CC is the most efficient parameter. Simulation in all the case emphasize that dimmer sensors coupled with louvers play an important role in increasing the electricity savings in a range of 12 to 15% more than the condition without dimmers.

Results of Case 4 highlight that mono crystalline PV cells are the most effective, but also have an increased cost impact. On the other hand, thin film cells are cost effective and also give an average rate of energy efficiency. Mono crystalline cells give 36.76% efficiency whereas thin films PV give 31.90% energy savings as compared to base case.

Based on results of each case, the most efficient case is simulated and results are tabulated. Efficient case shows 28% savings with respect to base case for louvers without PV, with dimmer sensor on. Whereas the results for louvers with PV is 40%.

The economic case gives the optimum configuration for cost effective louver conditions. This case shows 27.88% savings with respect to base case for louvers without PV, with dimmer sensor on. Whereas the results for louvers with PV is 34.92%.

The payback period of efficient case is 18 years, whereas that for economic case is 12 years. It is important to note that the rate of electricity tariff is heavily subsidized in UAE, and hence there is not much financial saving even if there is a good energy saving shown in this result.

6.3 Recommendations for usage

This dissertation focuses on the investigation of horizontal louvers not only from efficiency but also from economic point of view. The cabin of the office is a single module which can be used as a basis for energy calculations for any similar module of offices in Dubai. This module also creates a standard energy calculation for executing the design proposals for the whole building. Hence this dissertation can be further used to generate energy efficiency of the whole building on various facades.

Furthermore, the dissertation gives a comprehensive understanding of payback period of efficient as well as economic louver configurations. This can be used to generate value engineered solutions, in order to reduce the cost of horizontal louvers on building façade. Tracking angles of various degrees are simulated for different days. This can be used as a basis to generate intelligent louver configuration in the building. Dimmer sensor savings is the key findings of this dissertation. This can be used to execute the usage of dimmer sensor not only in the offices but also in the public areas of the building.

Overall it can be said that the energy saving calculations in the dissertation can be used as a model to bring about savings in a commercial building with varying stages of economic budget allowance.

6.4 Recommendations for future research

This dissertation focused on the simulation of a single cubicle, by enhancing the element of louvers on the south oriented façade. The study was limited to only this cubicle of the entire office, due to access of information of a single office. As future studies, the impact of louvers on the entire building can be studied in detail. The result generated by louvers with PV installed on the entire south facia, will be an interesting study in order to conclude the payback period of louvers integrated with PV cells.

The dissertation focused on horizontal louvers only. Different direction of louvers, including vertical louvers, interior louvers and sun shading fins can be studied in future, to compare the efficiency of these systems in the climatic conditions of Dubai.

Smart louvers and artificial sensor link to louvers can be established in continuation to this dissertation. This will be a futuristic proposal, since very few buildings in the UAE make use of intelligent façade as part of their functioning. Since this feature cannot be integrated with IES-VE, this dissertation only limits to generating a tracking angle routing.

The condition of simmer sensor being on and off is analyzed in this dissertation. There is a scope to explore the use of thermal sensors which can alter the indoor temperatures as per ambient conditions.

Overall, it can be said that the government can initiate more policies which support the use of energy efficient elements in the urban landscape. The generation of electricity can be shared in the neighborhood, and linked to a sustainable environment. Generation of electricity by a particular office in a commercial building, can be distributed to other offices, hence reducing the overall electricity consumption by the building. This practice is not very common in UAE due to regulation is electricity distribution in a community. Enhancing sustainability in the commercial buildings can lead to a more progressive goal towards sustainability goal of UAE.

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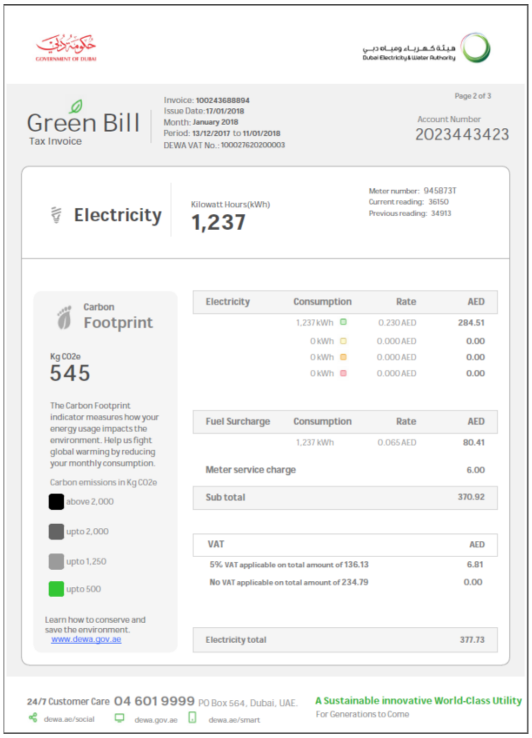
8. Appendices

8.1 Appendix 1

DEWA Electricity Bills 304, Al Mezan Building – Global Group of Companies.



Green Bill
Tax Invoice

Invoice: 100243688894
Issue Date: 17/01/2018
Month: January 2018
Period: 13/12/2017 to 11/01/2018
DEWA VAT No.: 100027620200003

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Account Number 2023443423

Electricity — Kilowatt Hours(kWh) 1,237

Meter number: 945873T
Current reading: 36150
Previous reading: 34913

Carbon Footprint
Kg CO2e
545

The Carbon Footprint indicator measures how your energy usage impacts the environment. Help us fight global warming by reducing your monthly consumption.

Carbon emissions in Kg CO2e: above 2,000; upto 2,000; upto 1,250; upto 500

Learn how to conserve and save the environment. www.dewa.gov.ae

Electricity	Consumption	Rate	AED
	1,237 kWh	0.230 AED	284.51
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00
Fuel Surcharge	**Consumption**	**Rate**	**AED**
	1,237 kWh	0.065 AED	80.41
Meter service charge			6.00
Sub total			370.92
VAT			**AED**
5% VAT applicable on total amount of 136.13			6.81
No VAT applicable on total amount of 234.79			0.00
Electricity total			377.73

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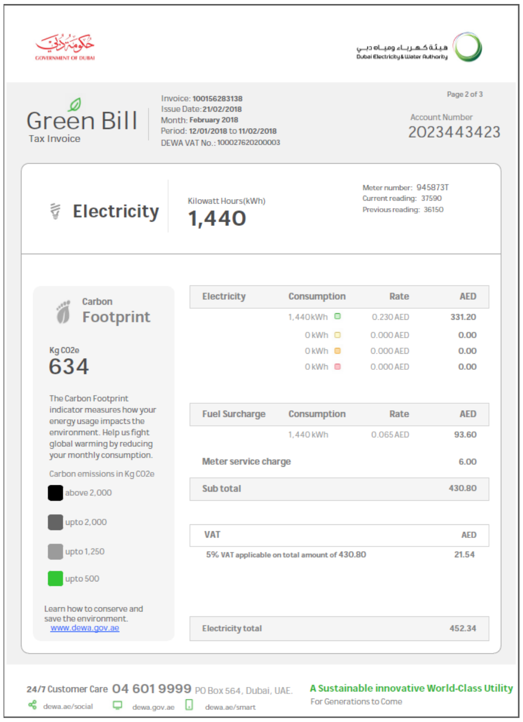

Green Bill
Tax Invoice

Invoice: 100156283138
Issue Date: 21/02/2018
Month: February 2018
Period: 12/01/2018 to 11/02/2018
DEWA VAT No.: 100027620200003

Page 2 of 3

Account Number 2023443423

Electricity — Kilowatt Hours(kWh) 1,440

Meter number: 945873T
Current reading: 37590
Previous reading: 36150

Carbon Footprint
Kg CO2e
634

The Carbon Footprint indicator measures how your energy usage impacts the environment. Help us fight global warming by reducing your monthly consumption.

Carbon emissions in Kg CO2e: above 2,000; upto 2,000; upto 1,250; upto 500

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Electricity	Consumption	Rate	AED
	1,440 kWh	0.230 AED	331.20
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00
Fuel Surcharge	**Consumption**	**Rate**	**AED**
	1,440 kWh	0.065 AED	93.60
Meter service charge			6.00
Sub total			430.80
VAT			**AED**
5% VAT applicable on total amount of 430.80			21.54
Electricity total			452.34

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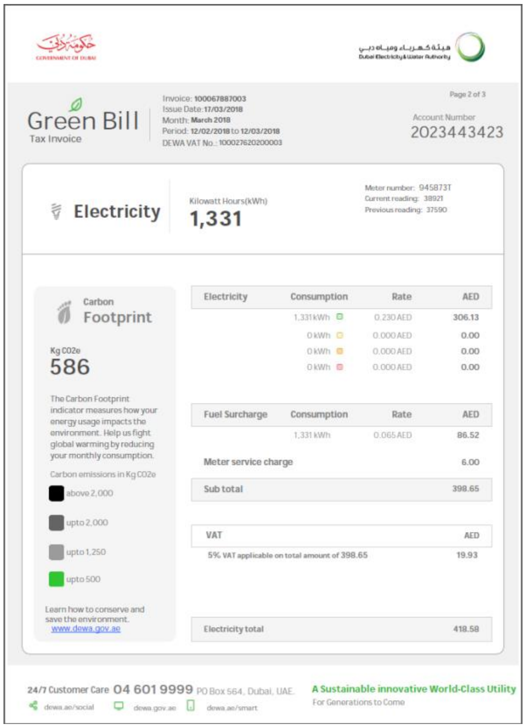

Green Bill
Tax Invoice

Invoice: 100067887003
Issue Date: 17/03/2018
Month: March 2018
Period: 12/02/2018 to 12/03/2018
DEWA VAT No.: 100027620200003

Page 2 of 3

Account Number 2023443423

Electricity — Kilowatt Hours(kWh) 1,331

Meter number: 945873T
Current reading: 38921
Previous reading: 37590

Carbon Footprint
Kg CO2e
586

The Carbon Footprint indicator measures how your energy usage impacts the environment. Help us fight global warming by reducing your monthly consumption.

Carbon emissions in Kg CO2e: above 2,000; upto 2,000; upto 1,250; upto 500

Learn how to conserve and save the environment. www.dewa.gov.ae

Electricity	Consumption	Rate	AED
	1,331 kWh	0.230 AED	306.13
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00
Fuel Surcharge	**Consumption**	**Rate**	**AED**
	1,331 kWh	0.065 AED	86.52
Meter service charge			6.00
Sub total			398.65
VAT			**AED**
5% VAT applicable on total amount of 398.65			19.93
Electricity total			418.58

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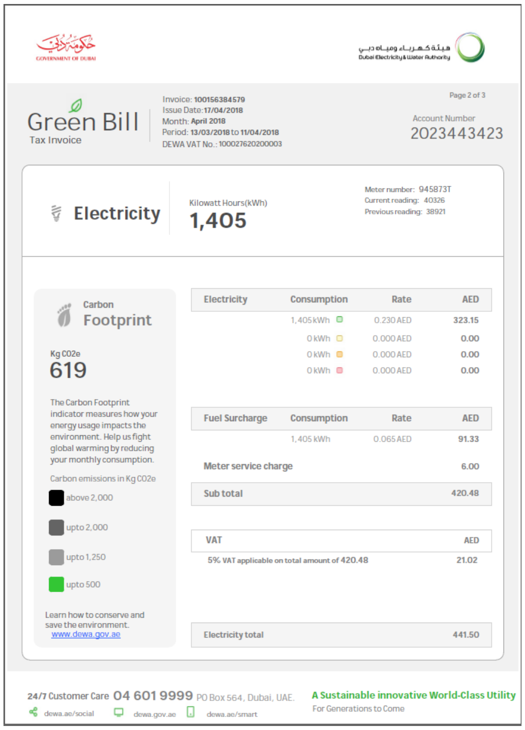

Green Bill
Tax Invoice

Invoice: 100156384579
Issue Date: 17/04/2018
Month: April 2018
Period: 13/03/2018 to 11/04/2018
DEWA VAT No.: 100027620200003

Page 2 of 3

Account Number 2023443423

Electricity — Kilowatt Hours(kWh) 1,405

Meter number: 945873T
Current reading: 40326
Previous reading: 38921

Carbon Footprint
Kg CO2e
619

The Carbon Footprint indicator measures how your energy usage impacts the environment. Help us fight global warming by reducing your monthly consumption.

Carbon emissions in Kg CO2e: above 2,000; upto 2,000; upto 1,250; upto 500

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Electricity	Consumption	Rate	AED
	1,405 kWh	0.230 AED	323.15
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00
Fuel Surcharge	**Consumption**	**Rate**	**AED**
	1,405 kWh	0.065 AED	91.33
Meter service charge			6.00
Sub total			420.48
VAT			**AED**
5% VAT applicable on total amount of 420.48			21.02
Electricity total			441.50

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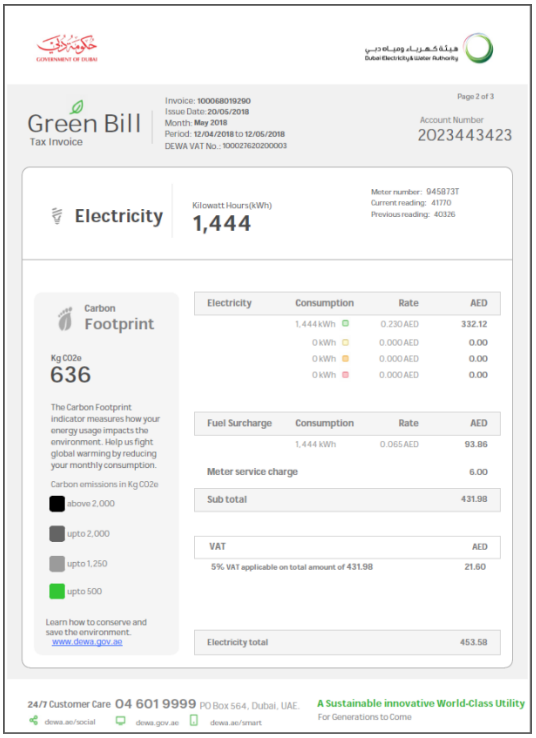

GOVERNMENT OF DUBAI

هيئة كهرباء ومياه دبي
Dubai Electricity & Water Authority

Page 2 of 3

Green Bill
Tax Invoice

Invoice: 100068019290
Issue Date: 20/05/2018
Month: May 2018
Period: 12/04/2018 to 12/05/2018
DEWA VAT No.: 100027620200003

Account Number 2023443423

Electricity Kilowatt Hours(kWh) **1,444**

Meter number: 945873T
Current reading: 41770
Previous reading: 40326

Carbon Footprint
Kg CO2e
636

The Carbon Footprint indicator measures how your energy usage impacts the environment. Help us fight global warming by reducing your monthly consumption.

Carbon emissions in Kg CO2e
above 2,000
upto 2,000
upto 1,250
upto 500

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Electricity	Consumption	Rate	AED
	1,444 kWh	0.230 AED	332.12
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00

Fuel Surcharge	Consumption	Rate	AED
	1,444 kWh	0.065 AED	93.86
Meter service charge			6.00
Sub total			431.98

VAT	AED
5% VAT applicable on total amount of 431.98	21.60
Electricity total	453.58

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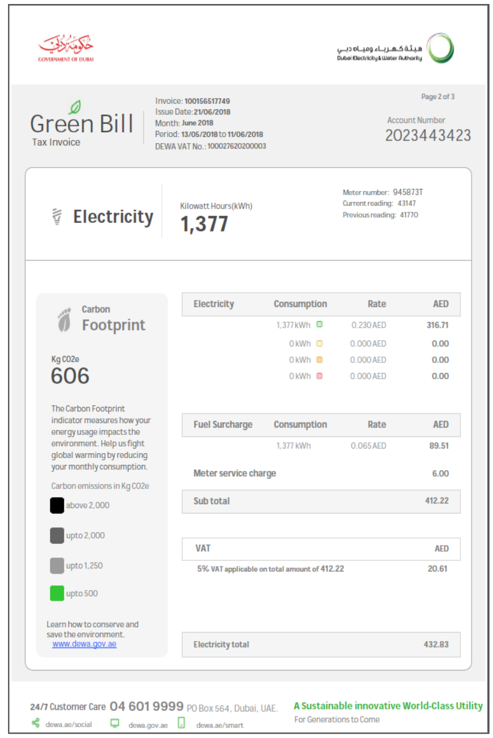

GOVERNMENT OF DUBAI

هيئة كهرباء ومياه دبي
Dubai Electricity & Water Authority

Page 2 of 3

Green Bill
Tax Invoice

Invoice: 100156517749
Issue Date: 21/06/2018
Month: June 2018
Period: 13/05/2018 to 11/06/2018
DEWA VAT No.: 100027620200003

Account Number 2023443423

Electricity Kilowatt Hours(kWh) **1,377**

Meter number: 945873T
Current reading: 43147
Previous reading: 41770

Carbon Footprint
Kg CO2e
606

The Carbon Footprint indicator measures how your energy usage impacts the environment. Help us fight global warming by reducing your monthly consumption.

Carbon emissions in Kg CO2e
above 2,000
upto 2,000
upto 1,250
upto 500

Learn how to conserve and save the environment.
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Electricity	Consumption	Rate	AED
	1,377 kWh	0.230 AED	316.71
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00

Fuel Surcharge	Consumption	Rate	AED
	1,377 kWh	0.065 AED	89.51
Meter service charge			6.00
Sub total			412.22

VAT	AED
5% VAT applicable on total amount of 412.22	20.61
Electricity total	432.83

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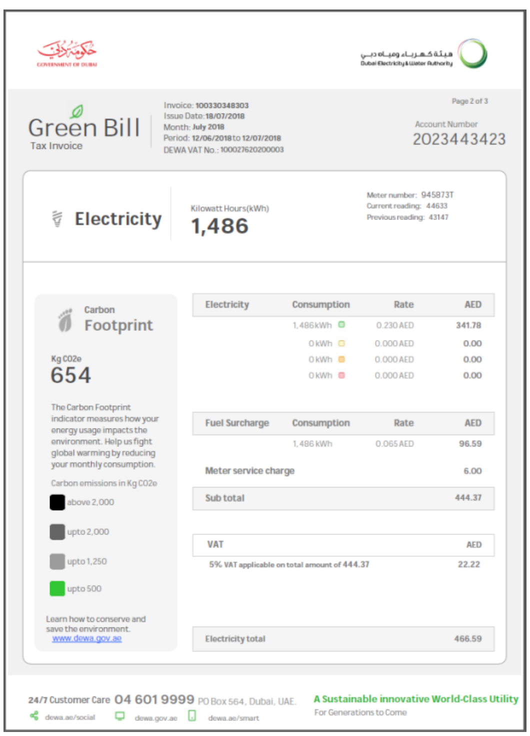

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هيئة كهرباء ومياه دبي
Dubai Electricity & Water Authority

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Green Bill
Tax Invoice

Invoice: 100330348303
Issue Date: 18/07/2018
Month: July 2018
Period: 12/06/2018 to 12/07/2018
DEWA VAT No.: 100027620200003

Account Number 2023443423

Electricity Kilowatt Hours(kWh) **1,486**

Meter number: 945873T
Current reading: 44633
Previous reading: 43147

Carbon Footprint
Kg CO2e
654

The Carbon Footprint indicator measures how your energy usage impacts the environment. Help us fight global warming by reducing your monthly consumption.

Carbon emissions in Kg CO2e
above 2,000
upto 2,000
upto 1,250
upto 500

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Electricity	Consumption	Rate	AED
	1,486 kWh	0.230 AED	341.78
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00

Fuel Surcharge	Consumption	Rate	AED
	1,486 kWh	0.065 AED	96.59
Meter service charge			6.00
Sub total			444.37

VAT	AED
5% VAT applicable on total amount of 444.37	22.22
Electricity total	466.59

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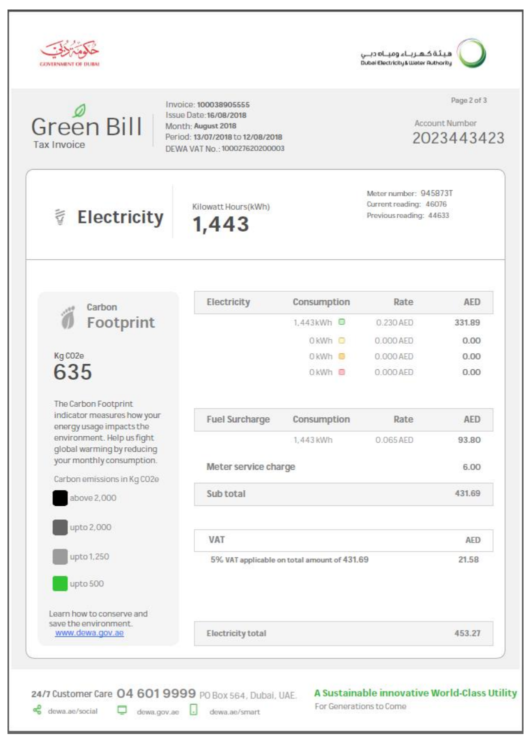

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هيئة كهرباء ومياه دبي
Dubai Electricity & Water Authority

Page 2 of 3

Green Bill
Tax Invoice

Invoice: 100038905555
Issue Date: 16/08/2018
Month: August 2018
Period: 13/07/2018 to 12/08/2018
DEWA VAT No.: 100027620200003

Account Number 2023443423

Electricity Kilowatt Hours(kWh) **1,443**

Meter number: 945873T
Current reading: 46076
Previous reading: 44633

Carbon Footprint
Kg CO2e
635

The Carbon Footprint indicator measures how your energy usage impacts the environment. Help us fight global warming by reducing your monthly consumption.

Carbon emissions in Kg CO2e
above 2,000
upto 2,000
upto 1,250
upto 500

Learn how to conserve and save the environment.
www.dewa.gov.ae

Electricity	Consumption	Rate	AED
	1,443 kWh	0.230 AED	331.89
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00

Fuel Surcharge	Consumption	Rate	AED
	1,443 kWh	0.065 AED	93.80
Meter service charge			6.00
Sub total			431.69

VAT	AED
5% VAT applicable on total amount of 431.69	21.58
Electricity total	453.27

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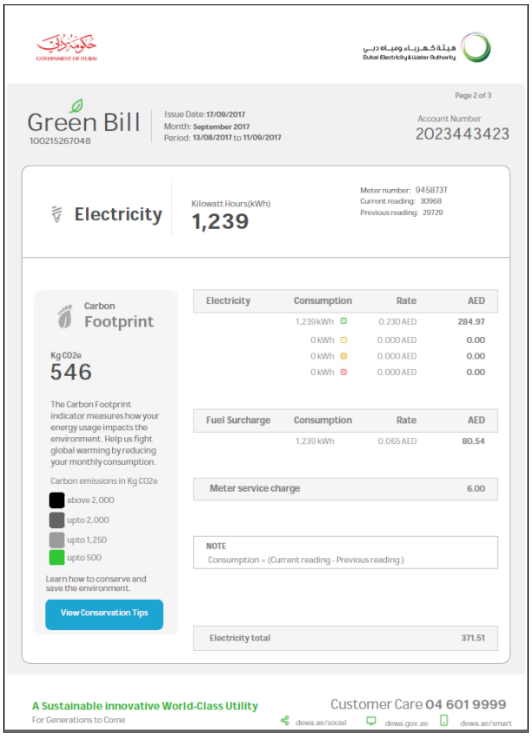

GOVERNMENT OF DUBAI

هيئة كهرباء ومياه دبي
Dubai Electricity & Water Authority

Page 2 of 3

Green Bill
100215267048

Issue Date: 17/09/2017
Month: September 2017
Period: 13/08/2017 to 11/09/2017

Account Number
2023443423

Electricity

Kilowatt Hours(kWh)
1,239

Meter number: 945873T
Current reading: 30968
Previous reading: 29729

Carbon Footprint

Kg CO2e
546

The Carbon Footprint indicator measures how your energy usage impacts the environment. Help us fight global warming by reducing your monthly consumption.

Carbon emissions in Kg CO2e
above 2,000
upto 2,000
upto 1,250
upto 500

Learn how to conserve and save the environment.

View Conservation Tips

Electricity	Consumption	Rate	AED
	1,239 kWh	0.230 AED	284.97
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00

Fuel Surcharge	Consumption	Rate	AED
	1,239 kWh	0.065 AED	80.54

Meter service charge 6.00

NOTE
Consumption = (Current reading - Previous reading)

Electricity total 371.51

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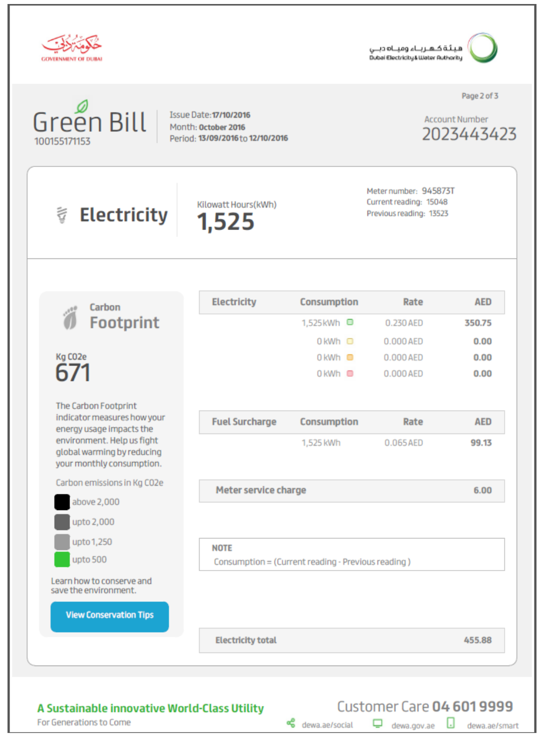

GOVERNMENT OF DUBAI

هيئة كهرباء ومياه دبي
Dubai Electricity & Water Authority

Page 2 of 3

Green Bill
100155171153

Issue Date: 17/10/2016
Month: October 2016
Period: 13/09/2016 to 12/10/2016

Account Number
2023443423

Electricity

Kilowatt Hours(kWh)
1,525

Meter number: 945873T
Current reading: 15048
Previous reading: 13523

Carbon Footprint

Kg CO2e
671

The Carbon Footprint indicator measures how your energy usage impacts the environment. Help us fight global warming by reducing your monthly consumption.

Carbon emissions in Kg CO2e
above 2,000
upto 2,000
upto 1,250
upto 500

Learn how to conserve and save the environment.

View Conservation Tips

Electricity	Consumption	Rate	AED
	1,525 kWh	0.230 AED	350.75
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00

Fuel Surcharge	Consumption	Rate	AED
	1,525 kWh	0.065 AED	99.13

Meter service charge 6.00

NOTE
Consumption = (Current reading - Previous reading)

Electricity total 455.88

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For Generations to Come

Customer Care 04 601 9999
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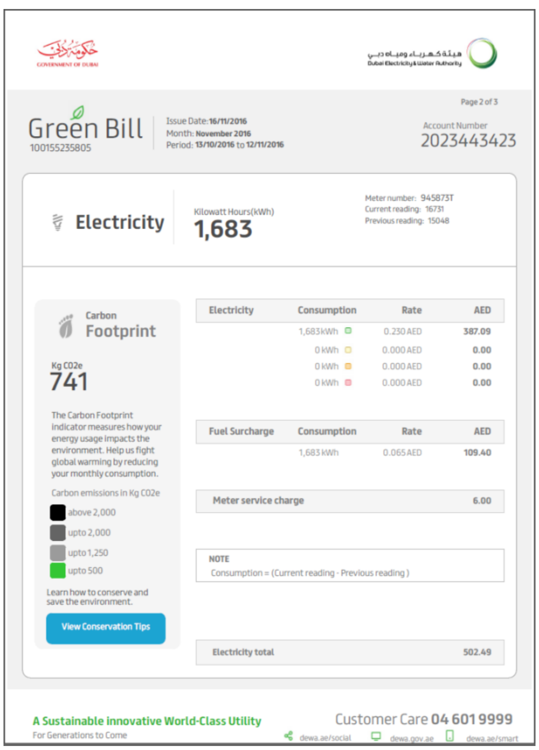

GOVERNMENT OF DUBAI

هيئة كهرباء ومياه دبي
Dubai Electricity & Water Authority

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Green Bill
100155235805

Issue Date: 16/11/2016
Month: November 2016
Period: 13/10/2016 to 12/11/2016

Account Number
2023443423

Electricity

Kilowatt Hours(kWh)
1,683

Meter number: 945873T
Current reading: 16731
Previous reading: 15048

Carbon Footprint

Kg CO2e
741

The Carbon Footprint indicator measures how your energy usage impacts the environment. Help us fight global warming by reducing your monthly consumption.

Carbon emissions in Kg CO2e
above 2,000
upto 2,000
upto 1,250
upto 500

Learn how to conserve and save the environment.

View Conservation Tips

Electricity	Consumption	Rate	AED
	1,683 kWh	0.230 AED	387.09
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00

Fuel Surcharge	Consumption	Rate	AED
	1,683 kWh	0.065 AED	109.40

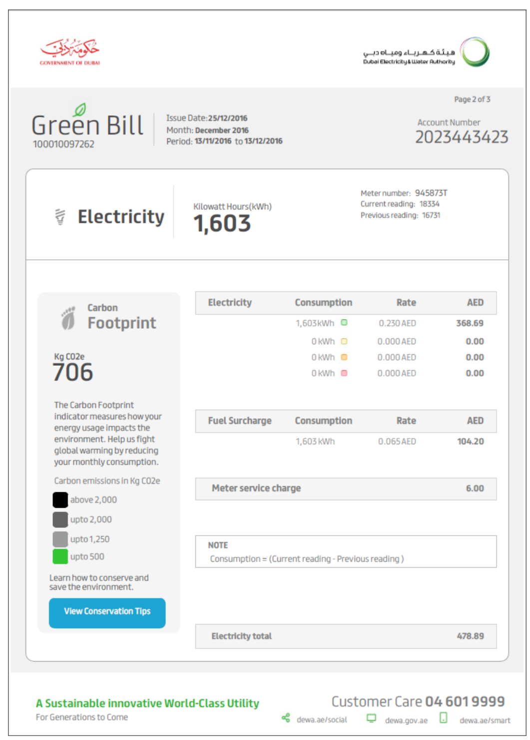
Meter service charge 6.00

NOTE
Consumption = (Current reading - Previous reading)

Electricity total 502.49

A Sustainable innovative World-Class Utility
For Generations to Come

Customer Care 04 601 9999
dewa.ae/social dewa.gov.ae dewa.ae/smart



GOVERNMENT OF DUBAI

هيئة كهرباء ومياه دبي
Dubai Electricity & Water Authority

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Green Bill
100010097262

Issue Date: 25/12/2016
Month: December 2016
Period: 13/11/2016 to 13/12/2016

Account Number
2023443423

Electricity

Kilowatt Hours(kWh)
1,603

Meter number: 945873T
Current reading: 18334
Previous reading: 16731

Carbon Footprint

Kg CO2e
706

The Carbon Footprint indicator measures how your energy usage impacts the environment. Help us fight global warming by reducing your monthly consumption.

Carbon emissions in Kg CO2e
above 2,000
upto 2,000
upto 1,250
upto 500

Learn how to conserve and save the environment.

View Conservation Tips

Electricity	Consumption	Rate	AED
	1,603 kWh	0.230 AED	368.69
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00
	0 kWh	0.000 AED	0.00

Fuel Surcharge	Consumption	Rate	AED
	1,603 kWh	0.065 AED	104.20

Meter service charge 6.00

NOTE
Consumption = (Current reading - Previous reading)

Electricity total 478.89

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8.2 Appendix 2

8.2.1 Case 1: Simulation results

Variable Angle: 20 degrees						
	Base Case	Louvers without PV_DS-OFF	Louvers without PV_DS-ON	Louvers with PV_Ds-OFF		Louvers with PV_Ds-ON
	Total electricity (MWh)	Total electricity (MWh)	Total electricity (MWh)	PV generated electricity (MWh)	(Total Elec - PV gen elec) Total Consumption	(Total Elec - PV gen elec) Total Consumption
Date	Base Case_DSoff.aps	20deg_DS-off.aps	20deg_DS-on.aps	20deg_PV_DSoff.aps		20deg_PV_DS-ON.aps
Jan 01-31	0.2893	0.2334	0.1889	-0.0238	0.2096	0.1651
Feb 01-28	0.2767	0.2169	0.1744	-0.0273	0.1896	0.1471
Mar 01-31	0.2965	0.2558	0.2081	-0.0239	0.2319	0.1842
Apr 01-30	0.2983	0.2803	0.2343	-0.0133	0.267	0.221
May 01-31	0.3166	0.3109	0.2649	-0.0066	0.3043	0.2583
Jun 01-30	0.3318	0.3285	0.2825	-0.0028	0.3257	0.2797
Jul 01-31	0.3576	0.352	0.3042	-0.0038	0.3482	0.3004
Aug 01-31	0.3534	0.3423	0.2963	-0.0107	0.3316	0.2856
Sep 01-30	0.3566	0.3239	0.2779	-0.0201	0.3038	0.2578
Oct 01-31	0.3549	0.2939	0.2494	-0.0306	0.2633	0.2188
Nov 01-30	0.3399	0.2784	0.2342	-0.0259	0.2525	0.2083
Dec 01-31	0.3166	0.2601	0.2142	-0.024	0.2361	0.1902
Summed total	3.8883	3.4764	2.9293	-0.2129	3.2635	2.7164
Savings w.r.t. Base Case		10.59%	24.66%		16.07%	30.14%

Variable Angle: 30 degrees						
	Base Case	Louvers without PV_DS-OFF	Louvers without PV_DS-ON	Louvers with PV_Ds-OFF		Louvers with PV_Ds-ON
	Total electricity (MWh)	Total electricity (MWh)	Total electricity (MWh)	PV generated electricity (MWh)	(Total Elec - PV gen elec) Total Consumption	(Total Elec - PV gen elec) Total Consumption
Date	Base Case_DSoff.aps	30deg_DS-OFF.aps	30deg_DS-ON.aps	30deg_PV_DS-OFF.aps		30deg_PV_DS-ON.aps
Jan 01-31	0.2893	0.2284	0.1838	-0.0283	0.2001	0.1555
Feb 01-28	0.2767	0.2129	0.1705	-0.029	0.1839	0.1415
Mar 01-31	0.2965	0.2534	0.2057	-0.0252	0.2282	0.1805
Apr 01-30	0.2983	0.2781	0.2321	-0.0139	0.2642	0.2182
May 01-31	0.3166	0.309	0.263	-0.0059	0.3031	0.2571
Jun 01-30	0.3318	0.3265	0.2805	-0.003	0.3235	0.2775
Jul 01-31	0.3576	0.3497	0.3019	-0.004	0.3457	0.2979
Aug 01-31	0.3534	0.3401	0.2941	-0.0099	0.3302	0.2842
Sep 01-30	0.3566	0.3218	0.2758	-0.0217	0.3001	0.2541
Oct 01-31	0.3549	0.2918	0.2472	-0.0314	0.2604	0.2158
Nov 01-30	0.3399	0.2729	0.2288	-0.0286	0.2443	0.2002
Dec 01-31	0.3166	0.2544	0.2085	-0.0264	0.228	0.1821
Summed total	3.8883	3.439	2.8919	-0.2273	3.2117	2.6646
Savings w.r.t. Base Case		11.56%	25.63%		17.40%	31.47%

Variable Angle: 40 degrees							
	Base Case		Louvers without PV_DS-OFF	Louvers without PV_DS-ON	Louvers with PV_Ds-OFF		Louvers with PV_Ds-ON
	Total electricity (MWh)		Total electricity (MWh)	Total electricity (MWh)	PV generated electricity (MWh)	(Total Elec - PV gen elec) Total Consumption	(Total Elec - PV gen elec) Total Consumption
Date	Base Case_DSoff.aps		40deg_DS-OFF.aps	40deg_PV_DS-ON.aps	40deg_PV_DS-OFF.aps		40deg_PV_DS-ON.aps
Jan 01-31	0.2893		0.226	0.1815	-0.0293	0.1967	0.1522
Feb 01-28	0.2767		0.2121	0.1696	-0.0307	0.1814	0.1389
Mar 01-31	0.2965		0.253	0.2053	-0.0228	0.2302	0.1825
Apr 01-30	0.2983		0.2778	0.2318	-0.015	0.2628	0.2168
May 01-31	0.3166		0.3088	0.2628	-0.0055	0.3033	0.2573
Jun 01-30	0.3318		0.3263	0.2803	-0.002	0.3243	0.2783
Jul 01-31	0.3576		0.3494	0.3016	-0.0036	0.3458	0.298
Aug 01-31	0.3534		0.3399	0.2939	-0.0113	0.3286	0.2826
Sep 01-30	0.3566		0.3216	0.2756	-0.0219	0.2997	0.2537
Oct 01-31	0.3549		0.2914	0.2469	-0.0359	0.2555	0.211
Nov 01-30	0.3399		0.2709	0.2268	-0.0281	0.2428	0.1987
Dec 01-31	0.3166		0.2516	0.2057	-0.028	0.2236	0.1777
Summed total	3.8883		3.4289	2.8818	-0.234	3.1949	2.6478
Savings w.r.t. Base Case			11.81%	25.89%		17.83%	31.90%

Variable Angle: 50 degrees							
	Base Case		Louvers without PV_DS-OFF	Louvers without PV_DS-ON	Louvers with PV_Ds-OFF		Louvers with PV_Ds-ON
	Total electricity (MWh)		Total electricity (MWh)	Total electricity (MWh)	PV generated electricity (MWh)	(Total Elec - PV gen elec) Total Consumption	(Total Elec - PV gen elec) Total Consumption
Date	Base Case_DSoff.aps		50deg_DS-OFF.aps	50deg_PV_DS-ON.aps	50deg_PV_DS-OFF.aps		50deg_PV_DS-ON.aps
Jan 01-31	0.2893		0.2255	0.1809	-0.029	0.1965	0.1519
Feb 01-28	0.2767		0.2127	0.1703	-0.0321	0.1806	0.1382
Mar 01-31	0.2965		0.2528	0.2051	-0.0255	0.2273	0.1796
Apr 01-30	0.2983		0.2776	0.2316	-0.0141	0.2635	0.2175
May 01-31	0.3166		0.3087	0.2627	-0.0059	0.3028	0.2568
Jun 01-30	0.3318		0.3262	0.2802	-0.002	0.3242	0.2782
Jul 01-31	0.3576		0.3493	0.3015	-0.0037	0.3456	0.2978
Aug 01-31	0.3534		0.3398	0.2938	-0.0095	0.3303	0.2843
Sep 01-30	0.3566		0.3215	0.2755	-0.0223	0.2992	0.2532
Oct 01-31	0.3549		0.2917	0.2472	-0.0325	0.2592	0.2147
Nov 01-30	0.3399		0.2707	0.2266	-0.0309	0.2398	0.1957
Dec 01-31	0.3166		0.2507	0.2048	-0.0278	0.2229	0.177
Summed total	3.8883		3.4271	2.88	-0.2353	3.1918	2.6447
Savings w.r.t. Base Case			11.86%	25.93%		17.91%	31.98%

Variable Angle: 60 degrees										
	Base Case		Louvers without PV_DS-OFF		Louvers without PV_DS-ON		Louvers with PV_Ds-OFF			Louvers with PV_Ds-ON
	Total electricity (MWh)		Total electricity (MWh)		Total electricity (MWh)		PV generated electricity (MWh)	(Total Elec - PV gen elec) Total Consumption		(Total Elec - PV gen elec) Total Consumption
Date	Base Case_DSoff.aps		60deg_DS-OFF.aps		60deg_PV_DS-ON.aps		60deg_PV_DS-OFF.aps			60deg_PV_DS-ON.aps
Jan 01-31	0.2893		0.2264		0.1818		-0.028	0.1984		0.1538
Feb 01-28	0.2767		0.2152		0.1727		-0.0299	0.1853		0.1428
Mar 01-31	0.2965		0.2528		0.2051		-0.0267	0.2261		0.1784
Apr 01-30	0.2983		0.2775		0.2315		-0.0133	0.2642		0.2182
May 01-31	0.3166		0.3086		0.2626		-0.0053	0.3033		0.2573
Jun 01-30	0.3318		0.3262		0.2802		-0.002	0.3242		0.2782
Jul 01-31	0.3576		0.3492		0.3014		-0.0034	0.3458		0.298
Aug 01-31	0.3534		0.3397		0.2937		-0.0108	0.3289		0.2829
Sep 01-30	0.3566		0.3215		0.2755		-0.0202	0.3013		0.2553
Oct 01-31	0.3549		0.2948		0.2503		-0.0308	0.264		0.2195
Nov 01-30	0.3399		0.2722		0.228		-0.0321	0.2401		0.1959
Dec 01-31	0.3166		0.2512		0.2053		-0.0303	0.2209		0.175
Summed total	3.8883		3.4353		2.8882		-0.2328	3.2025		2.6554
Savings w.r.t. Base Case			11.65%		25.72%			17.64%		31.71%

8.2.2 Case 2: Simulation results

Variable Width: 50mm

	Base Case	Louvers without PV_DS-OFF	Louvers without PV_DS-ON	Louvers with PV_Ds-OFF		Louvers with PV_Ds-ON
	Total electricity (MWh)	Total electricity (MWh)	Total electricity (MWh)	PV generated electricity (MWh)	(Total Elec - PV gen elec) Total Consumption	(Total Elec - PV gen elec) Total Consumption
Date	Base Case_DSoff.aps	50W_DS-off.aps	50W_DS-on.aps	50W_PV_DSoff.aps		50W_PV_DS-ON.aps
Jan 01-31	0.2893	0.2522	0.2077	-0.0164	0.2358	0.1913
Feb 01-28	0.2767	0.2394	0.1969	-0.0158	0.2236	0.1811
Mar 01-31	0.2965	0.2669	0.2192	-0.0162	0.2507	0.203
Apr 01-30	0.2983	0.2801	0.2341	-0.0115	0.2686	0.2226
May 01-31	0.3166	0.3101	0.2641	-0.0049	0.3052	0.2592
Jun 01-30	0.3318	0.3275	0.2815	-0.0014	0.3261	0.2801
Jul 01-31	0.3576	0.3513	0.3035	-0.0029	0.3484	0.3006
Aug 01-31	0.3534	0.3413	0.2953	-0.0095	0.3318	0.2858
Sep 01-30	0.3566	0.3279	0.2818	-0.018	0.3099	0.2638
Oct 01-31	0.3549	0.3175	0.273	-0.0177	0.2998	0.2553
Nov 01-30	0.3399	0.2996	0.2554	-0.0169	0.2827	0.2385
Dec 01-31	0.3166	0.2784	0.2325	-0.014	0.2644	0.2185
Summed total	3.8883	3.5922	3.0451	-0.1452	3.447	2.8999
Savings w.r.t. Base Case		7.62%	21.69%		11.35%	25.42%

Variable Width 90mm

	Base Case	Louvers without PV_DS-OFF	Louvers without PV_DS-ON	Louvers with PV_Ds-OFF		Louvers with PV_Ds-ON
	Total electricity (MWh)	Total electricity (MWh)	Total electricity (MWh)	PV generated electricity (MWh)	(Total Elec - PV gen elec) Total Consumption	(Total Elec - PV gen elec) Total Consumption
Date	Base Case_DSoff.aps	90W_DS-OFF.aps	90W_PV_DS-ON.aps	90W_PV_DS-OFF.aps		90W_PV_DS-ON.aps
Jan 01-31	0.2893	0.226	0.1815	-0.0293	0.1967	0.1522
Feb 01-28	0.2767	0.2121	0.1696	-0.0307	0.1814	0.1389
Mar 01-31	0.2965	0.253	0.2053	-0.0228	0.2302	0.1825
Apr 01-30	0.2983	0.2778	0.2318	-0.015	0.2628	0.2168
May 01-31	0.3166	0.3088	0.2628	-0.0055	0.3033	0.2573
Jun 01-30	0.3318	0.3263	0.2803	-0.002	0.3243	0.2783
Jul 01-31	0.3576	0.3494	0.3016	-0.0036	0.3458	0.298
Aug 01-31	0.3534	0.3399	0.2939	-0.0113	0.3286	0.2826
Sep 01-30	0.3566	0.3216	0.2756	-0.0219	0.2997	0.2537
Oct 01-31	0.3549	0.2914	0.2469	-0.0359	0.2555	0.211
Nov 01-30	0.3399	0.2709	0.2268	-0.0281	0.2428	0.1987
Dec 01-31	0.3166	0.2516	0.2057	-0.028	0.2236	0.1777
Summed total	3.8883	3.4289	2.8818	-0.234	3.1949	2.6478
Savings w.r.t. Base Case		11.81%	25.89%		17.83%	31.90%

Variable Width 120 mm						
	Base Case	Louvers without PV_DS-OFF	Louvers without PV_DS-ON	Louvers with PV_Ds-OFF		Louvers with PV_Ds-ON
	Total electricity (MWh)	Total electricity (MWh)	Total electricity (MWh)	PV generated electricity (MWh)	(Total Elec - PV gen elec) Total Consumption	(Total Elec - PV gen elec) Total Consumption
Date	Base Case_DSoff.aps	120W_DS-off.aps	120W_DS-on.aps	120W_PV_DSoff.aps		120W_PV_DS-ON.aps
Jan 01-31	0.2893	0.2094	0.1649	-0.0353	0.1741	0.1296
Feb 01-28	0.2767	0.2053	0.1629	-0.0363	0.169	0.1266
Mar 01-31	0.2965	0.2514	0.2037	-0.0244	0.227	0.1793
Apr 01-30	0.2983	0.2766	0.2306	-0.0132	0.2634	0.2174
May 01-31	0.3166	0.3081	0.2621	-0.0065	0.3016	0.2556
Jun 01-30	0.3318	0.3257	0.2797	-0.0032	0.3225	0.2765
Jul 01-31	0.3576	0.3484	0.3006	-0.0044	0.344	0.2962
Aug 01-31	0.3534	0.3391	0.2931	-0.0122	0.3269	0.2809
Sep 01-30	0.3566	0.321	0.275	-0.0208	0.3002	0.2542
Oct 01-31	0.3549	0.2897	0.2452	-0.0359	0.2538	0.2093
Nov 01-30	0.3399	0.2559	0.2118	-0.0306	0.2253	0.1812
Dec 01-31	0.3166	0.2326	0.1867	-0.0355	0.1971	0.1512
Summed total	3.8883	3.3633	2.8163	-0.2584	3.1049	2.5579
Savings w.r.t. Base Case		13.50%	27.57%		20.15%	34.22%

Variable Width 150 mm						
	Base Case	Louvers without PV_DS-OFF	Louvers without PV_DS-ON	Louvers with PV_Ds-OFF		Louvers with PV_Ds-ON
	Total electricity (MWh)	Total electricity (MWh)	Total electricity (MWh)	PV generated electricity (MWh)	(Total Elec - PV gen elec) Total Consumption	(Total Elec - PV gen elec) Total Consumption
Date	Base Case_DSoff.aps	150W_DS-off.aps	150W_DS-on.aps	150W_PV_DSoff.aps		150W_PV_DS-ON.aps
Jan 01-31	0.2893	0.2075	0.163	-0.036	0.1715	0.127
Feb 01-28	0.2767	0.2046	0.1622	-0.0374	0.1672	0.1248
Mar 01-31	0.2965	0.2505	0.2028	-0.0265	0.224	0.1763
Apr 01-30	0.2983	0.2759	0.2298	-0.0148	0.2611	0.215
May 01-31	0.3166	0.3076	0.2616	-0.0075	0.3001	0.2541
Jun 01-30	0.3318	0.3253	0.2793	-0.0047	0.3206	0.2746
Jul 01-31	0.3576	0.3478	0.3	-0.0059	0.3419	0.2941
Aug 01-31	0.3534	0.3386	0.2926	-0.0117	0.3269	0.2809
Sep 01-30	0.3566	0.3206	0.2746	-0.0235	0.2971	0.2511
Oct 01-31	0.3549	0.2893	0.2448	-0.0295	0.2598	0.2153
Nov 01-30	0.3399	0.2545	0.2104	-0.0385	0.216	0.1719
Dec 01-31	0.3166	0.2297	0.1838	-0.0399	0.1898	0.1439
Summed total	3.8883	3.3519	2.8049	-0.276	3.0759	2.5289
Savings w.r.t. Base Case		13.80%	27.86%		20.89%	34.96%

Variable Width 180 mm										
	Base Case		Louvers without PV_DS-OFF		Louvers without PV_DS-ON		Louvers with PV_Ds-OFF			Louvers with PV_Ds-ON
	Total electricity (MWh)		Total electricity (MWh)		Total electricity (MWh)		PV generated electricity (MWh)	(Total Elec - PV gen elec) Total Consumption		(Total Elec - PV gen elec) Total Consumption
Date	Base Case_DSoff.aps		180W_DS-off.aps		180W_DS-on.aps		180W_PV_DSoff.aps			180W_PV_DS-ON.aps
Jan 01-31	0.2893		0.2071		0.1626		-0.0401	0.167		0.1225
Feb 01-28	0.2767		0.2044		0.1619		-0.036	0.1684		0.1259
Mar 01-31	0.2965		0.2501		0.2024		-0.0247	0.2254		0.1777
Apr 01-30	0.2983		0.2754		0.2294		-0.0169	0.2585		0.2125
May 01-31	0.3166		0.3074		0.2614		-0.0086	0.2988		0.2528
Jun 01-30	0.3318		0.3251		0.2791		-0.0047	0.3204		0.2744
Jul 01-31	0.3576		0.3474		0.2996		-0.0055	0.3419		0.2941
Aug 01-31	0.3534		0.3383		0.2923		-0.0141	0.3242		0.2782
Sep 01-30	0.3566		0.3204		0.2743		-0.0226	0.2978		0.2517
Oct 01-31	0.3549		0.2891		0.2446		-0.0396	0.2495		0.205
Nov 01-30	0.3399		0.2541		0.21		-0.0378	0.2163		0.1722
Dec 01-31	0.3166		0.2291		0.1832		-0.0412	0.1879		0.142
Summed total	3.8883		3.3479		2.8009		-0.2918	3.0561		2.5091
Savings w.r.t. Base Case			13.90%		27.97%			21.40%		35.47%

8.2.3 Case 3: Simulation results

Variable CC: 80mm						
	Base Case	Louvers without PV_DS-OFF	Louvers without PV_DS-ON	Louvers with PV_Ds-OFF		Louvers with PV_Ds-ON
	Total electricity (MWh)	Total electricity (MWh)	Total electricity (MWh)	PV generated electricity (MWh)	(Total Elec - PV gen elec) Total Consumption	(Total Elec - PV gen elec) Total Consumption
Date	Base Case_DSoff.aps	80CC_DS-off.aps	80CC_DS-on.aps	80CC_PV_DSoff.aps		80CC_PV_DS-ON.aps
Jan 01-31	0.2893	0.2071	0.1626	-0.0391	0.168	0.1235
Feb 01-28	0.2767	0.2044	0.1619	-0.0321	0.1723	0.1298
Mar 01-31	0.2965	0.2501	0.2024	-0.0247	0.2254	0.1777
Apr 01-30	0.2983	0.2755	0.2295	-0.014	0.2615	0.2155
May 01-31	0.3166	0.3074	0.2614	-0.0061	0.3013	0.2553
Jun 01-30	0.3318	0.3251	0.2791	-0.0021	0.323	0.277
Jul 01-31	0.3576	0.3474	0.2997	-0.0037	0.3437	0.296
Aug 01-31	0.3534	0.3384	0.2924	-0.0114	0.327	0.281
Sep 01-30	0.3566	0.3204	0.2744	-0.0215	0.2989	0.2529
Oct 01-31	0.3549	0.2892	0.2446	-0.0394	0.2498	0.2052
Nov 01-30	0.3399	0.2542	0.2101	-0.0348	0.2194	0.1753
Dec 01-31	0.3166	0.2292	0.1833	-0.0393	0.1899	0.144
Summed total	3.8883	3.3484	2.8014	-0.2684	3.08	2.533
Savings w.r.t. Base Case		13.89%	27.95%		20.79%	34.86%

Variable CC: 90mm						
	Base Case	Louvers without PV_DS-OFF	Louvers without PV_DS-ON	Louvers with PV_Ds-OFF		Louvers with PV_Ds-ON
	Total electricity (MWh)	Total electricity (MWh)	Total electricity (MWh)	PV generated electricity (MWh)	(Total Elec - PV gen elec) Total Consumption	(Total Elec - PV gen elec) Total Consumption
Date	Base Case_DSoff.aps	90CC_DS-off.aps	90CC_DS-on.aps	90CC_PV_DSoff.aps		90CC_PV_DS-ON.aps
Jan 01-31	0.2893	0.2074	0.1629	-0.0398	0.1676	0.1231
Feb 01-28	0.2767	0.2046	0.1621	-0.0343	0.1703	0.1278
Mar 01-31	0.2965	0.2505	0.2028	-0.0257	0.2248	0.1771
Apr 01-30	0.2983	0.2758	0.2298	-0.0145	0.2613	0.2153
May 01-31	0.3166	0.3076	0.2616	-0.0056	0.302	0.256
Jun 01-30	0.3318	0.3253	0.2792	-0.0021	0.3232	0.2771
Jul 01-31	0.3576	0.3477	0.2999	-0.0037	0.344	0.2962
Aug 01-31	0.3534	0.3386	0.2926	-0.0109	0.3277	0.2817
Sep 01-30	0.3566	0.3205	0.2745	-0.0226	0.2979	0.2519
Oct 01-31	0.3549	0.2893	0.2448	-0.0395	0.2498	0.2053
Nov 01-30	0.3399	0.2545	0.2103	-0.0376	0.2169	0.1727
Dec 01-31	0.3166	0.2296	0.1837	-0.0374	0.1922	0.1463
Summed total	3.8883	3.3512	2.8042	-0.2738	3.0774	2.5304
Savings w.r.t. Base Case		13.81%	27.88%		20.85%	34.92%

Variable CC: 120mm						
	Base Case	Louvers without PV_DS-OFF	Louvers without PV_DS-ON	Louvers with PV_Ds-OFF		Louvers with PV_Ds-ON
	Total electricity (MWh)	Total electricity (MWh)	Total electricity (MWh)	PV generated electricity (MWh)	(Total Elec - PV gen elec) Total Consumption	(Total Elec - PV gen elec) Total Consumption
Date	Base Case_DSoff.aps	120CC_DS-off.aps	120CC_DS-on.aps	120CC_PV_DSoff.aps		120CC_PV_DS-ON.aps
Jan 01-31	0.2893	0.211	0.1665	-0.0348	0.1762	0.1317
Feb 01-28	0.2767	0.2056	0.1631	-0.0311	0.1745	0.132
Mar 01-31	0.2965	0.2516	0.2039	-0.0244	0.2272	0.1795
Apr 01-30	0.2983	0.2768	0.2308	-0.0145	0.2623	0.2163
May 01-31	0.3166	0.3082	0.2622	-0.0062	0.302	0.256
Jun 01-30	0.3318	0.3258	0.2798	-0.0021	0.3237	0.2777
Jul 01-31	0.3576	0.3486	0.3008	-0.0038	0.3448	0.297
Aug 01-31	0.3534	0.3392	0.2932	-0.011	0.3282	0.2822
Sep 01-30	0.3566	0.3211	0.2751	-0.0227	0.2984	0.2524
Oct 01-31	0.3549	0.2898	0.2453	-0.0378	0.252	0.2075
Nov 01-30	0.3399	0.2571	0.2129	-0.0351	0.222	0.1778
Dec 01-31	0.3166	0.2352	0.1893	-0.0364	0.1988	0.1529
Summed total	3.8883	3.37	2.8229	-0.2597	3.1103	2.5632
Savings w.r.t. Base Case		13.33%	27.40%		20.01%	34.08%

Variable CC: 150mm						
	Base Case	Louvers without PV_DS-OFF	Louvers without PV_DS-ON	Louvers with PV_Ds-OFF		Louvers with PV_Ds-ON
	Total electricity (MWh)	Total electricity (MWh)	Total electricity (MWh)	PV generated electricity (MWh)	(Total Elec - PV gen elec) Total Consumption	(Total Elec - PV gen elec) Total Consumption
Date	Base Case_DSoff.aps	150CC_DS-OFF.aps	150CC_PV_DS-ON.aps	150CC_PV_DS-OFF.aps		150CC_PV_DS-ON.aps
Jan 01-31	0.2893	0.226	0.1815	-0.0293	0.1967	0.1522
Feb 01-28	0.2767	0.2121	0.1696	-0.0307	0.1814	0.1389
Mar 01-31	0.2965	0.253	0.2053	-0.0228	0.2302	0.1825
Apr 01-30	0.2983	0.2778	0.2318	-0.015	0.2628	0.2168
May 01-31	0.3166	0.3088	0.2628	-0.0055	0.3033	0.2573
Jun 01-30	0.3318	0.3263	0.2803	-0.002	0.3243	0.2783
Jul 01-31	0.3576	0.3494	0.3016	-0.0036	0.3458	0.298
Aug 01-31	0.3534	0.3399	0.2939	-0.0113	0.3286	0.2826
Sep 01-30	0.3566	0.3216	0.2756	-0.0219	0.2997	0.2537
Oct 01-31	0.3549	0.2914	0.2469	-0.0359	0.2555	0.211
Nov 01-30	0.3399	0.2709	0.2268	-0.0281	0.2428	0.1987
Dec 01-31	0.3166	0.2516	0.2057	-0.028	0.2236	0.1777
Summed total	3.8883	3.4289	2.8818	-0.234	3.1949	2.6478
Savings w.r.t. Base Case		11.81%	25.89%		17.83%	31.90%

Variable CC: 180mm						
	Base Case	Louvers without PV_DS-OFF	Louvers without PV_DS-ON	Louvers with PV_Ds-OFF		Louvers with PV_Ds-ON
	Total electricity (MWh)	Total electricity (MWh)	Total electricity (MWh)	PV generated electricity (MWh)	(Total Elec - PV gen elec) Total Consumption	(Total Elec - PV gen elec) Total Consumption
Date	Base Case_DSoff.aps	180CC_DS-OFF.aps	180CC_PV_DS-ON.aps	180CC_PV_DS-OFF.aps		180CC_PV_DS-ON.aps
Jan 01-31	0.2893	0.2354	0.1908	-0.0252	0.2102	0.1656
Feb 01-28	0.2767	0.2221	0.1796	-0.024	0.1981	0.1556
Mar 01-31	0.2965	0.2542	0.2065	-0.0238	0.2304	0.1827
Apr 01-30	0.2983	0.2785	0.2325	-0.0145	0.264	0.218
May 01-31	0.3166	0.3092	0.2632	-0.0059	0.3033	0.2573
Jun 01-30	0.3318	0.3267	0.2807	-0.0019	0.3248	0.2788
Jul 01-31	0.3576	0.35	0.3022	-0.0037	0.3463	0.2985
Aug 01-31	0.3534	0.3404	0.2944	-0.0113	0.3291	0.2831
Sep 01-30	0.3566	0.322	0.276	-0.0204	0.3016	0.2556
Oct 01-31	0.3549	0.3002	0.2557	-0.031	0.2692	0.2247
Nov 01-30	0.3399	0.2812	0.2371	-0.0253	0.2559	0.2118
Dec 01-31	0.3166	0.2611	0.2152	-0.0242	0.2369	0.191
Summed total	3.8883	3.4811	2.934	-0.2113	3.2698	2.7227
Savings w.r.t. Base Case		10.47%	24.54%		15.91%	29.98%

8.2.4 Case 4: Simulation results

Variable PV Type: Monocrystalline						
	Base Case	Louvers without PV_DS-OFF	Louvers without PV_DS-ON	Louvers with PV_Ds-OFF		Louvers with PV_Ds-ON
	Total electricity (MWh)	Total electricity (MWh)	Total electricity (MWh)	PV generated electricity (MWh)	(Total Elec - PV gen elec) Total Consumption	(Total Elec - PV gen elec) Total Consumption
Date	Base Case_DSoff.aps	Mono_DS-off.aps	Mono_DS-on.aps	Mono_PV_DSoff.aps		Mono_PV_DS-ON.aps
Jan 01-31	0.2893	0.226	0.1815	-0.0534	0.1726	0.1281
Feb 01-28	0.2767	0.2121	0.1696	-0.0557	0.1564	0.1139
Mar 01-31	0.2965	0.253	0.2053	-0.0416	0.2114	0.1637
Apr 01-30	0.2983	0.2778	0.2318	-0.0271	0.2507	0.2047
May 01-31	0.3166	0.3088	0.2628	-0.01	0.2988	0.2528
Jun 01-30	0.3318	0.3263	0.2803	-0.0036	0.3227	0.2767
Jul 01-31	0.3576	0.3494	0.3016	-0.0064	0.343	0.2952
Aug 01-31	0.3534	0.3399	0.2939	-0.0203	0.3196	0.2736
Sep 01-30	0.3566	0.3216	0.2756	-0.0391	0.2825	0.2365
Oct 01-31	0.3549	0.2914	0.2469	-0.064	0.2274	0.1829
Nov 01-30	0.3399	0.2709	0.2268	-0.0508	0.2201	0.176
Dec 01-31	0.3166	0.2516	0.2057	-0.051	0.2006	0.1547
Summed total	3.8883	3.4289	2.8818	-0.4229	3.006	2.4589
Savings w.r.t. Base Case		11.81%	25.89%		22.69%	36.76%

Variable PV Type: Polycrystalline						
	Base Case	Louvers without PV_DS-OFF	Louvers without PV_DS-ON	Louvers with PV_Ds-OFF		Louvers with PV_Ds-ON
	Total electricity (MWh)	Total electricity (MWh)	Total electricity (MWh)	PV generated electricity (MWh)	(Total Elec - PV gen elec) Total Consumption	(Total Elec - PV gen elec) Total Consumption
Date	Base Case_DSoff.aps	Poly_DS-OFF.aps	Poly_DS-ON.aps	Poly_PV_DS-OFF.aps		Poly_PV_DS-ON.aps
Jan 01-31	0.2893	0.226	0.1815	-0.0451	0.1809	0.1364
Feb 01-28	0.2767	0.2121	0.1696	-0.0471	0.165	0.1225
Mar 01-31	0.2965	0.253	0.2053	-0.0352	0.2178	0.1701
Apr 01-30	0.2983	0.2778	0.2318	-0.023	0.2548	0.2088
May 01-31	0.3166	0.3088	0.2628	-0.0084	0.3004	0.2544
Jun 01-30	0.3318	0.3263	0.2803	-0.0031	0.3232	0.2772
Jul 01-31	0.3576	0.3494	0.3016	-0.0054	0.344	0.2962
Aug 01-31	0.3534	0.3399	0.2939	-0.0171	0.3228	0.2768
Sep 01-30	0.3566	0.3216	0.2756	-0.0331	0.2885	0.2425
Oct 01-31	0.3549	0.2914	0.2469	-0.0542	0.2372	0.1927
Nov 01-30	0.3399	0.2709	0.2268	-0.043	0.2279	0.1838
Dec 01-31	0.3166	0.2516	0.2057	-0.0431	0.2085	0.1626
Summed total	3.8883	3.4289	2.8818	-0.3578	3.0711	2.524
Savings w.r.t. Base Case		11.81%	25.89%		21.02%	35.09%

Variable PV Type: Thin Film						
	Base Case	Louvers without PV_DS-OFF	Louvers without PV_DS-ON	Louvers with PV_Ds-OFF		Louvers with PV_Ds-ON
	Total electricity (MWh)	Total electricity (MWh)	Total electricity (MWh)	PV generated electricity (MWh)	(Total Elec - PV gen elec) Total Consumption	(Total Elec - PV gen elec) Total Consumption
Date	Base Case_DSoff.aps	ThinFilm_DS-OFF.aps	ThinFilm_PV_DS-ON.aps	ThinFilm_PV_DS-OFF.aps		ThinFilm_PV_DS-ON.aps
Jan 01-31	0.2893	0.226	0.1815	-0.0293	0.1967	0.1522
Feb 01-28	0.2767	0.2121	0.1696	-0.0307	0.1814	0.1389
Mar 01-31	0.2965	0.253	0.2053	-0.0228	0.2302	0.1825
Apr 01-30	0.2983	0.2778	0.2318	-0.015	0.2628	0.2168
May 01-31	0.3166	0.3088	0.2628	-0.0055	0.3033	0.2573
Jun 01-30	0.3318	0.3263	0.2803	-0.002	0.3243	0.2783
Jul 01-31	0.3576	0.3494	0.3016	-0.0036	0.3458	0.298
Aug 01-31	0.3534	0.3399	0.2939	-0.0113	0.3286	0.2826
Sep 01-30	0.3566	0.3216	0.2756	-0.0219	0.2997	0.2537
Oct 01-31	0.3549	0.2914	0.2469	-0.0359	0.2555	0.211
Nov 01-30	0.3399	0.2709	0.2268	-0.0281	0.2428	0.1987
Dec 01-31	0.3166	0.2516	0.2057	-0.028	0.2236	0.1777
Summed total	3.8883	3.4289	2.8818	-0.234	3.1949	2.6478
Savings w.r.t. Base Case		11.81%	25.89%		17.83%	31.90%

8.2.5 Efficient Case Comparison: Simulation Results

90MM CC, 90MM WIDTH						
	Base Case	Louvers without PV_DS-OFF	Louvers without PV_DS-ON	Louvers with PV_Ds-OFF		Louvers with PV_Ds-ON
	Total electricity (MWh)	Total electricity (MWh)	Total electricity (MWh)	PV generated electricity (MWh)	(Total Elec - PV gen elec) Total Consumption	(Total Elec - PV gen elec) Total Consumption
Date	Base Case_DSoff.aps	90CC,W_DS-off.aps	90CC,W_DS-on.aps	90CC,W_PV_DSoff.aps		90CC,W_PV_DS-ON.aps
Jan 01-31	0.2893	0.2074	0.1629	-0.0398	0.1676	0.1231
Feb 01-28	0.2767	0.2046	0.1621	-0.0343	0.1703	0.1278
Mar 01-31	0.2965	0.2505	0.2028	-0.0257	0.2248	0.1771
Apr 01-30	0.2983	0.2758	0.2298	-0.0145	0.2613	0.2153
May 01-31	0.3166	0.3076	0.2616	-0.0056	0.302	0.256
Jun 01-30	0.3318	0.3253	0.2792	-0.0021	0.3232	0.2771
Jul 01-31	0.3576	0.3477	0.2999	-0.0037	0.344	0.2962
Aug 01-31	0.3534	0.3386	0.2926	-0.0109	0.3277	0.2817
Sep 01-30	0.3566	0.3205	0.2745	-0.0226	0.2979	0.2519
Oct 01-31	0.3549	0.2893	0.2448	-0.0395	0.2498	0.2053
Nov 01-30	0.3399	0.2545	0.2103	-0.0376	0.2169	0.1727
Dec 01-31	0.3166	0.2296	0.1837	-0.0374	0.1922	0.1463
Summed total	3.8883	3.3512	2.8042	-0.2738	3.0774	2.5304
Savings w.r.t. Base Case		13.81%	27.88%		20.85%	34.92%

150MM CC, 150MM WIDTH						
	Base Case	Louvers without PV_DS-OFF	Louvers without PV_DS-ON	Louvers with PV_Ds-OFF		Louvers with PV_Ds-ON
	Total electricity (MWh)	Total electricity (MWh)	Total electricity (MWh)	PV generated electricity (MWh)	(Total Elec - PV gen elec) Total Consumption	(Total Elec - PV gen elec) Total Consumption
Date	Base Case_DSoff.a	150CC,W_DS-off.aps	150CC,W_DS-on.aps	150CC,W_PV_DS off.aps		150CC,W_PV_DS-ON.aps
Jan 01-31	0.2893	0.2075	0.163	-0.0375	0.17	0.1255
Feb 01-28	0.2767	0.2046	0.1622	-0.0354	0.1692	0.1268
Mar 01-31	0.2965	0.2506	0.2028	-0.0257	0.2249	0.1771
Apr 01-30	0.2983	0.2759	0.2299	-0.0152	0.2607	0.2147
May 01-31	0.3166	0.3076	0.2616	-0.007	0.3006	0.2546
Jun 01-30	0.3318	0.3253	0.2793	-0.0046	0.3207	0.2747
Jul 01-31	0.3576	0.3478	0.3	-0.0058	0.342	0.2942
Aug 01-31	0.3534	0.3386	0.2926	-0.0121	0.3265	0.2805
Sep 01-30	0.3566	0.3206	0.2746	-0.0238	0.2968	0.2508
Oct 01-31	0.3549	0.2893	0.2448	-0.0336	0.2557	0.2112
Nov 01-30	0.3399	0.2545	0.2104	-0.0357	0.2188	0.1747
Dec 01-31	0.3166	0.2297	0.1838	-0.037	0.1927	0.1468
Summed total	3.8883	3.352	2.805	-0.2733	3.0787	2.5317
Savings w.r.t. Base Case		13.79%	27.86%		20.82%	34.89%

8.3 Appendix 3

Cost Impact quotes for simple payback period: Comparison for Efficient case

AlunoTec

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LOUVRE WINDOW QUOTATION

To: Ms. Saniya Bordawekar — **Date:** September 6th, 2018

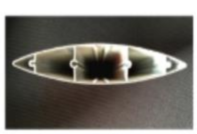
No.	Item Name	Material&Specification	Window Size (mm)		Quantity			Sub-Total
			Length	Width	㎡/Piece	Unit	Unit Cost (AED)	Total (AED)
AP-F150	Aluminum Fixed Louvre 	**Material:** Option 1 6063T5 Aluminum Alloy 1. Blade: 150x35mm, 1.15mm thk; 20 pcs 2. Frame: 100x50mm, 2.5mm thk; 5 pcs 3. Endcap: 150x35mm, 3mm thk; 4. Internal L shape connectors: 94x34mm, 2.5mm thk; 5. Aluminum Brackets 6. Stainless steel screws **Colour&Finish:** Powdercoated: any RAL colour	3000	3000	9.00	1	410	AED 3690
							Total	**AED 3690**

No.	Item Name	Material&Specification	Window Size (mm)		Quantity			Sub-Total
			Length	Width	㎡/Piece	Unit	Unit Cost (AED)	Total (AED)
AP-F90	Aluminum Fixed Louvre 	**Material:** Option 2 6063T6 Aluminum Alloy 1. Blade: 90x35mm, 1.15mm thk; 33 pcs 2. Frame: 100x50mm, 2.5mm thk; 5 pcs 3. Endcap: 150x35mm, 3mm thk; 4. Internal L shape connectors: 94x34mm, 2.5mm thk; 5. Aluminum Brackets 6. Stainless steel screws **Colour&Finish:** Powdercoated: any RAL colour	3000	3000	8.91	1	350	AED 3118.5
							Total	**AED 3118.5**

1. Price: Includes cost of Installtion, as per approved shop drawings by the client.
2. Payment term: 30% T/T deposit, 40% on material delivery, balance upon installation
3. Delivery Time: 15-20 work days after receiving the deposit & confirming drawings.
4. Quality Control: Workshop inspect before shipment.
5. Packing: Crate box packaging with protective measures.
6. Validity: 15 days, quotation is subject to exchange rate,material cost etc.

Pictures of louvre and package for your reference:

150x35x1.15mm louvre



Aluminum louvre with sliver color

Workshop overview

Crate Box Packaging

Cost Impact quotes for simple payback period: Efficient and Economic Case

AlunoTec

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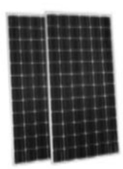
LOUVRE WINDOW QUOTATION

To: Ms. Saniya Bordawekar **Date:** September 6th, 2018

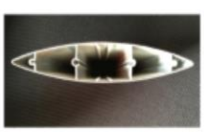
No.	Item Name	Material&Specification	Window Size (mm)		Quantity			Sub-Total
			Length	Width	㎡/Piece	Unit	Unit Cost (AED)	Total (AED)
AP-M-90	Mono Solar Cells 	**Material:** Louver integrated PV cells 6063T5 Aluminum Alloy 1. Blade: 90x35mm, 1.15mm thk; 33 pcs 2. Rated Maximum Power at STC: 250 W 3. Module Efficiency- 15- 18 %	3000	3000	8.91	1	950	AED 8464.5
							Total	**AED 8464.5**

No.	Item Name	Material&Specification	Window Size (mm)		Quantity			Sub-Total
			Length	Width	㎡/Piece	Unit	Unit Cost (AED)	Total (AED)
AP-T-90	Thin Film Cells 	**Material:** Louver integrated PV cells 6063T6 Aluminum Alloy 1. Blade: 90x35mm, 1.15mm thk; 33 pcs 2. Rated Maximum Power at STC: 250 W 3. Module efficiency- 7-8%	3000	3000	8.91	1	550	AED 4900.5
							Total	**AED 4900.5**

1. Price: Includes cost of Installtion, as per approved shop drawings by the client.
2. Payment term: 30% T/T deposit, 40% on material delivery, balance upon installation
3. Delivery Time: 15-20 work days after receiving the deposit & confirming drawings.
4. Quality Control: Workshop inspect before shipment.
5. Packing: Crate box packaging with protective measures.
6. Validity: 15 days, quotation is subject to exchange rate,material cost etc.

Pictures of louvre and package for your reference:

90x35x1.15mm louvre



Aluminum louvre with sliver color

Workshop overview

Crate Box Packaging