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

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ABSTRACT
Studies on the effect of external fixed louvers shading device on office buildings energy performance in UAE climate condition have shown that the louvers application caused a significant energy saving potential for the South, East and West orientations. However, the different louvers configurations and properties estimate a different performance in energy saving. This research is aimed to explore the influence of changing the louvers Aspect Ratio AR, louvers color, louvers slat tilt angles and louvers material on the energy performance of office building in Dubai city. A virtual office unit model with the same parameters of existing office building in Dubai was used to evaluate the energy consumption performance of external fixed louvers for the South, North, East and West orientations. The IES-VE computer simulation software that was used to predict the energy consumption in order to evaluate the effect of different louvers configurations and properties in energy performance.

This study found that the louvers shade application with the same AR value of Louvers Width / and Louvers Spacing distance (LW/LS) resulted with approximately the same effect in energy saving. This is important so we can focus on the effect of AR only without having to test the different combination of LS and LW that give similar AR reading. The study found that the optimum energy saving reduction was recorded by using louvers (AR=3.0) with semitransparent material and Visible Transmittance (VT) of 50% was achieved with a 33.16% annual average energy savings in comparison with the base case (without louvers shading) for the South orientation. However this VT value allows penetrating the maximum defused sun light and protects the building facade from the direct sun radiation. The optimum louvers AR configuration was AR=3.0 with annual average percentage of reduction in energy saving of 29.33%, 25.06% and 23.47% for the South, East and West orientations, respectively. The study found that the changing in louvers AR is more efficient in energy saving than the changing in louvers angles.

KEYWORDS: Energy Saving, Building Façade, External louvers, shading device, IES-VE

1. INTRODUCTION

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

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

Several studies on solar control in a building’s facade suggest that different applications of external and internal shading devices can create a significant improvement in the building’s energy consumption. Presently, emphasis should be placed on building technology to improve a new building’s ability to deal with the climate in the most energy efficient way, especially focusing on the façade of the building, Aboulnaga, (2006) reported that the world energy agency in 2004 postulated the world’s energy needs will increase 60% by 2030 and two thirds of this increase will come from developing countries.

Using external louvers as a shading device in the building can help to reduce the negative effect of solar radiation by ensuring the maximum amount of daylight reaches the interior whilst minimizing heat transfer in order to reduce the total energy consumption of the building by minimizing the use of artificial light. Palmero-Marrero and Oliveira, (2009) studied the feasibility of using external louvers in order to provide a sufficient amount of luminance from natural sunlight and minimize the use of artificial light to reduce the electricity consumption and reduce the need for air conditioning by avoiding the overheating caused by solar radiation. The study found that the total power consumption could be reduced as a result of reducing the need for artificial lighting. On the other hand the use of some form of light reflector could enhance the interior visual comfort condition by avoiding glare and controlling the quality and the quantity of natural daylight from the different orientations. The main purpose of using this innovative shading system solution in a bright lighting condition is to avoid heat and glare, thus reducing the energy demand. Solar radiation and natural daylight are the main factors affecting the building’s energy performance by controlling the thermal comfort, visual comfort and energy demand. However increasing the daylight, efficiency results in lower lighting electric and cooling demand (HVAC) electric load. Li and Wong (2007) illustrates the effect of optimum daylight design solution for the lighting and cooling electric demand in the office buildings reach 70% of the total electricity consumption. In addition to this the cooling demand is reduced when reducing the lighting generated heat gain.

2. Methodology

Many research methodologies were used to test the performance of the shading device. Each of these methods has negative and positive features. In the past the researchers relayed on manual tools with mathematical calculations to assess the shading performance. Nowadays modern research methods are being applied with different technologies and with a high accurate results such as the laboratory scaled model simulation, filed experimental measurement, computer simulation method and the computer mathematical calculations method. Freewan Et Al (2008) and Ho Et Al (2008) used two different research methodologies in order to compare them and reduce errors to achieve the reliable results. These two papers used the laboratory simulation with a physical scaled model, experimental measurement and the computer simulation with a virtual one. This is considered as good example to verify and validate the computer simulation of using shading devices in building façade. The output results of the computer simulation were similar to the experimental results; therefore the simulation software can be used in any light simulation with high validity and accuracy.

The computer simulation method were chosen for this study to test the optimum external louvers shading design in terms of energy saving and the glare effect. This method was chosen due to a number of advantages using a computer simulation method in terms of saving time and money. The possibility of simulating in any latitude, or using any material properties, with validity and the widely options for changing parameters. Crawley Et Al, (2008) conducted a comparison of the features and capability of twenty major building energy simulation programs, this comparison found that The IES-VE software achieved a high score as comprehensive environmental simulation software. With this in mind, the IES-VE was chosen due the ease of use and quick feedback capabilities as the VE-Toolkits, also provides users the ability to input exact building data and manipulate models.

2.1. Simulation model & Building description

This simulation study will take a typical high rise office building in Dubai with the consideration of the existing building parameters and the current construction materials properties. The following part consist of a description of the chosen existing office building as well as the construction materials properties. Saba office tower is an ideal existing case study due the building parameters, building orientation, construction materials and building layout features. Main curtain glazed façades were constructed from all the building sides. The building material data of Saba tower has been used in IES-VE construction materials database in order to simulate a typical single office unit for the South, East and West façade as been illustrated in figure 1.

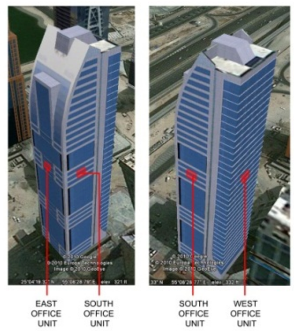

Figure.1 Four selected typical offices unit position from Saba Tower on the south, east and west facade.

This construction materials layers define the thermal properties for building elements which has an important role in the building thermal performance. The construction materials have been used in IES-VE database for the following building elements as been highlighted in figure 2.

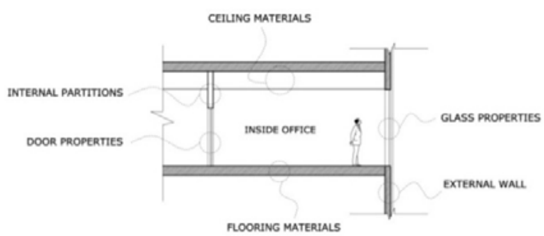

Figure.2 Six building elements were considered in order to simulate a single office unit.

Some key parameters of construction materials properties have been used in the IES_VE construction database. This construction data will affect the simulation results. Therefore, listed below are key parameters in which have been mentioned in ASHRAE Fundamentals handbook, (2009) and (IES materials menu) in order to achieve accurate analysis simulations. The lists includes glass shading coefficient, U-value, thermal coefficient, transparency, conductivity and emissivity.

2.2 Office model:

A typical office room with rectangular shape of 4m (length) X 7m (width) X 3.6m (height) was constructed by using the modelIT tools on IES in order to test the effect of external louvers shading device on the buildings energy performance, full glazed curtain wall façade from flooring to ceiling level with dimension of 2.7m (height) X 4m (length) has been shown in figure 4 (a). External horizontal louvers with different diminutions properties were constructed for the south façade test, vertical louvers will be used for the east and west façade simulation test has been recommended in the daylight guidelines provided by Building Technology Department at the Lawrence Berkeley National Laboratory cited in Hammad and Abu-Hijleh (2010) as figure 3.

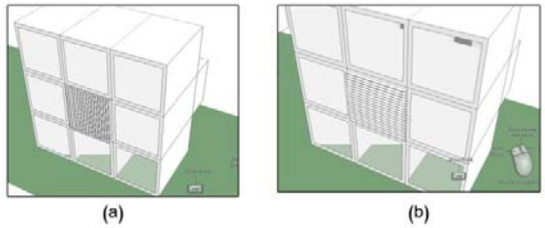

Figure.3 Office unit, virtual model on IES. (a) Vertical external louvers installation for the East and West façade, (b) horizontal external louvers installation for the south façade.

The office was assumed to accommodate two work stations with two computer units with an assumed power of 370W two workers with maximum sensible gain 90.0 W/person and Internal lighting luminance of 500 Lux was fixed based on the Illuminating Engineering Society of North America (IESNA) standards (block, 2000) cited in Hammad and Abu-Hijleh (2010). The cooling system was assumed to be on all the time with constant internal temperature set at 24° and 0.25 air changes/hour infiltration rates. Fluorescent luminaries lighting unit was fixed on ceiling level at 2.8m high with installed power density of 2.2W/m²/100lux.

2.3 Office operation time and weather data:

The working operation time schedule assumed for the use of office during the week working days (Sunday to Thursday) from 07:00am to 07:00pm, however it's very important for the simulation process to schedule the working hours for the HVAC system, Lighting System and the computers equipment. APpro tools of IES-VE programs allow the user to create different operation profiles for each operating system individually with different operation periods like daily profile, weekly profile and annual profile. In this study three different profiles were created for different operation system. The office lights are modulated to achieve minimum of 500lux from the combined natural daylight and artificial light with daily operation time from 07:00am to 07:00pm during the weekly working days in the first profile. The second profile was completed for the computer equipment and people with operation time of 07:00am to 07:00pm during the weekly working days. Finally the HVAC system with continuously working operation of 24hours a day during the week days as Saba tower scenario and usual office towers scenario in Dubai. On the IES-VE program the APlocate is the weather and site location editor for the heat loss and heat gain (ApacheCalc), ASHRAE heat balance method (ApacheLoads), ApachSim, SunCast and Radiance. For the purpose of this investigation the Dubai weather database was chosen as a APlocate location in order to select 4 different days representing the 4 different seasons to test the building office energy consumption performance with different external louvers configuration. 4 different days in 4 different seasons were selected to represent the whole year. These 4 days were selected with the consideration of the latitude seasons, daily working days (not including the weekends) and the atmosphere cloud cover rang were selected days that had a clear sky condition. These 4 days were, 21st of March, 20th of June, 20th of September and 15th of December.

2.4 Defining the research parameters:

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

-. The Aspect Ratio (AR) between the Louvers Width (LW) and Louvers Spacing distance (LS) with 0° slat angle for all cases, figure 4 (a) Illustrate these diminutions in louvers design. Lighting and cooling loads of the interior space are affected by adjusting this ratio due the sun angle and position changes from time to time and form season to season. The four different Aspect Ratio will be tested: AR=1.0 (LW=LS), AR=0.5, (2LW=LS), AR=2.0, (LW=2LS), AR=3.0 (LW=3LS).

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

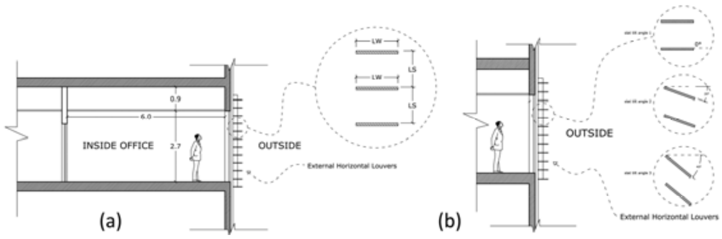

Figure.4. (a) The ratio between the louvers spacing distance (LS) and louvers width (LW). (b) Louvers slate tilt angles.

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

- Louvers slate tilt angle: This variable will be tested in three louvers tilt slat angle 0° (the standard angle case), 20° and 40° with the case louvers ratio AR=1 (LW=LS) for the South orientation only. The selection of these two angles value was considered to keep the visual relation between the inside and outside. Figure 4 (b) shows the tested louvers slat tilt angles.

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

2.3 Matrix for simulation cases:
In order to have a comprehensive understanding for the proposed simulation cases of this investigation, the following description briefly explains the simulation cases scenarios:

- Base case simulation: this simulation case will be without shading device installation in order to present the current situation in Saba office tower and in most Dubai office scenarios. The running simulation will be for the North, East, West and South façade during the four selected days.

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

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

- Louvers with slat angle 0° (the standard angle case), 20° and 40° with the case louvers ratio (LW) = (LS) for the South orientation only. Semitransparent materials test this for the South orientation with the louvers ratio (LW) = (LS) and 0° slat tilt angle. Finally, this simulation study is important to note that the analysis for the typical selected office from Saba tower runs without any consideration of the surrounding building and the building site urban shading properties.

2.4 Model validation:

The cooling load was simulated for the same model parameters with CARRIER HAP4.2 thermal simulation software by a mechanical engineer in order to verify the results obtained from the base case. IES was used the ASHREA load calculations to obtain the cooling load of the base case during the operations time from 07:00am to 07:00pm in September. The cooling load the both tools show approximately the same results with small differences due to the different use in weather data in IES database and CARRIER HAP4.2.

3. Results & discussion

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

3.1 Louvers Aspect Ratio results AR = (LW/LS):

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

3.2. Seasons energy saving variations

The results in figure 5 show the percentage of reduction in energy saving comparison with the base case (without louvers shading). The chart shows a very small energy saving for the North orientation compared with the other orientations. This huge difference cased due to the sun path that has been disused before. The chart shows that the percentage of the energy saving reduction for the South orientation was greater than the East and West orientations during March, September and December. During June the energy saving percentage for the South orientation was lower than the East and West due the high azimuth sun angle of this month which protects the south orientation from the direct solar radiation has been mentioned before. The result also shows a slight different in energy saving performance for the East and West during the four seasons. In contrast the result shows a strong variation in energy saving percentage for the South orientation from season to season. The difference in energy saving for the South orientation could be due to the difference of the suns path, the amount of direct solar radiation and the weather in general from season to season. For the North orientation scenario the energy saving performance reaches the maximum during June, and the sun is facing the North orientation only during this month the whole year. Full simulations data measurements require 12 tables like that 1056 rows of measurements represent the hourly simulations over the course of four seasons. The South, East and West orientations simulations group results are listed as the four selected days 21st of March, 20th of June, 20th of September and 15th of December.

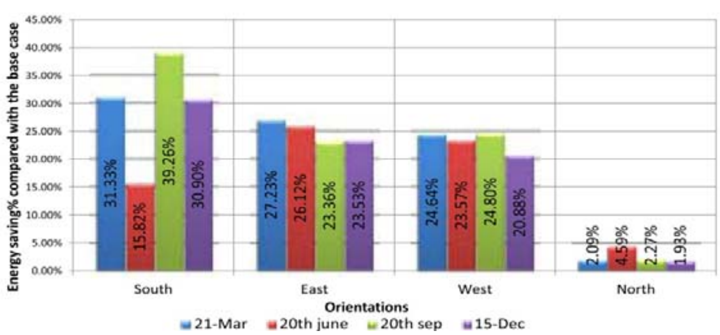

Figure 5. Energy saving% for louvers AR=3 compared with the base case for the West, East and South orientations during the four seasons.

3.3. Daytime energy saving variations:

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

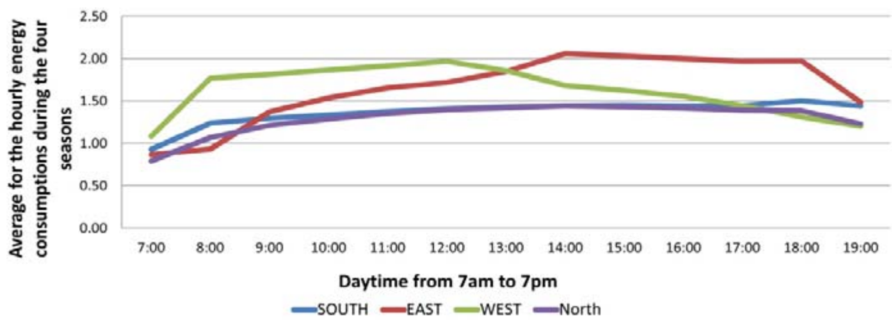

Figure 6. Hourly average energy consumptions for the louvers AR=3.0 during the four seasons for the South, East and west orientations.

3.4 Comparison between the louvers configurations scenarios:

For the South orientation, the chart in figure 7 shows a significant variation in energy saving potential during the four seasons. The result shows that the energy saving reduction in June was lower compared to the other orientations. This could be explained by the high sun azimuth angle during this month. On contrast the optimum energy reduction with the whole louvers installations scenario was during September. Although the sun azimuth angle during December lower than September but the amount of direct solar radiation can reach 950 Lux (w/m2) in September and only 700 Lux (w/m2) during December. This explains the reason of the variation in energy saving reduction during the different seasons. louvers AR=3 and semitransparent material with 30% VT has an (33.95%), (18.61%), (40.75.27%) and (34.41%) energy saving on 21st of March, 20th of June, 20th of September and 15th of December, respectively. The case with VT 50% has an (35.13%), (19.06%), (42.80%) and (35.65%) energy saving on 21st of March, 20th of June, 20th of September and 15th of December, respectively. The case with VT 75% has an (32.70%), (18.80%), (40.13%) and (33.48%) energy saving on 21st of March, 20th of June, 20th of September and 15th of December, respectively. In conclusions the south orientation results illustrate the main factors which have a significant effect in the louvers shading performance from season to season. The optimum energy saving reduction compared with the base case is the louvers AR=3 with semi-transparent material VT=50.

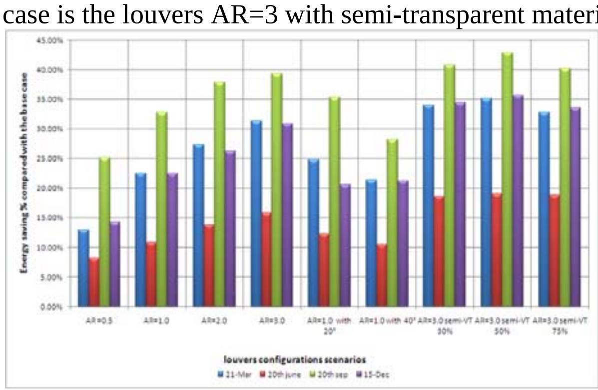

Figure7. Energy saving reduction for louvers scenario compared with the base case for the South orientation.

The effect of different louver shading configurations and properties was determined by comparing the total daily direct solar radiation input of each orientation. As results in figure 8 the percentage energy saving by each louvers configuration in comparison to without shading (the base case) various as the following:

The results show a significant reduction in energy saving by changing the louvers width (LW) to the louver spacing distance (LS) ratio. The chart in figure 8 shows that the AR=3.0 is the optimum louvers AR in comparison to base case in the all orientations during the whole year seasons with annual average energy saving 29.33%, 25.06% and 23.47% for the South, East and West orientations, respectively. The simulations test the effect of colours in louvers shading aimed to provide additional information on the contribution of reflected sun light in the interior illuminance. The effect of reflectivity created by this color could be compared and determined by the amount of transmitted reflected sun light. The results for the South, East and West orientations shows a very small reduction value of energy saving 0.353% to 0.415% compared with the standard martial color for louvers by changing the louvers color from opaque material to mirror material during the whole year seasons as shown in figure 8. In terms of using semi-transparent materials, the simulations results shows an optimum reduction of 33.16% annual average energy saving by using louvers with semi-transparent material of VT 50% for the optimum louvers AR=3 compared with the base case has been illustrated in figure 8. The simulation test illustrate that the VT value for the semitransparent material has the optimum energy saving in VT 50%, this VT value allows penetrating the maximum defused sun light and at the same time protects the window from the direct sun radiation. On the other hand the VT 75% allows the direct sun radiation to penetrate inside the building which increases the cooling demand. Moreover the Louvers slat tilt angles results show a reduction in energy saving by changing the louvers slat tilt angles. The chart in figure 8 shows that the optimum louvers slat tilt angle is 20°. The annual average energy saving reduction Compared with the base case scenario was 22.13%, 23.22%, and 20.29% for 0°, 20° and 40°, respectively. This indicates that the louvers angle 20°.has the optimum static angle in terms of energy saving caused due the different sun azimuth angle during the different seasons. Consequently, the different louvers static angles between 0° to 40° are not too effective in terms of the energy saving, as long as it is within the correct range. It must be noted that the angles tested were for the standard louvers AR=1.

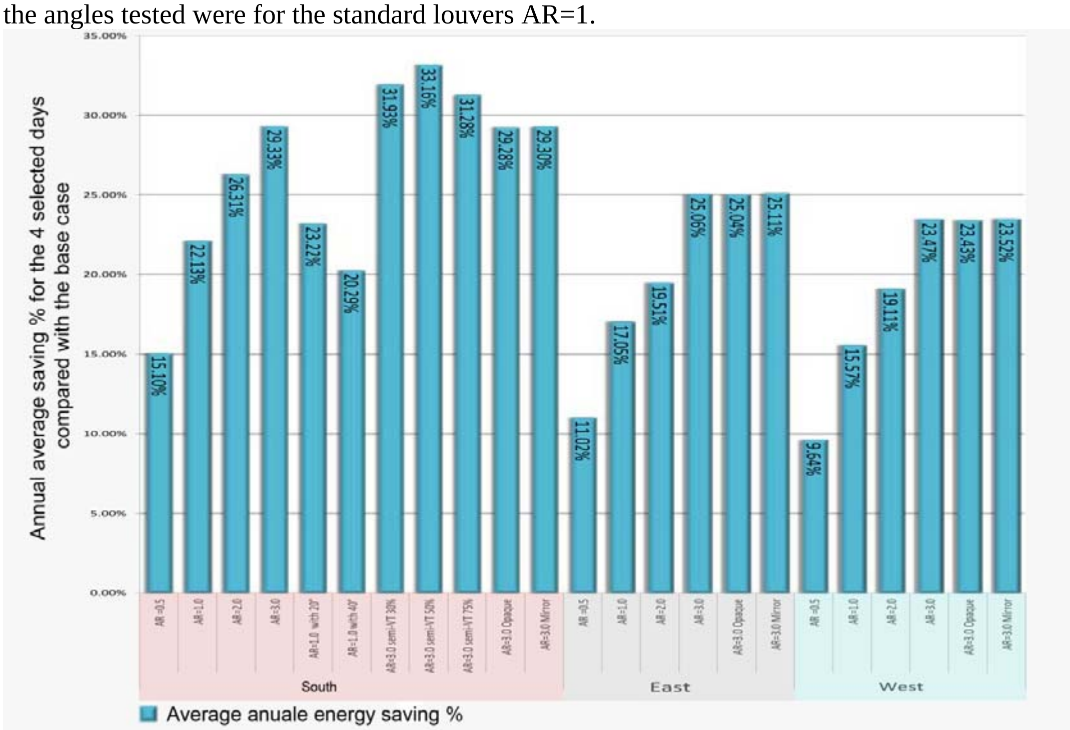

Figure8. Average annual energy saving% for all louvers scenario compared with the base case for the West, East and South orientations.

4. CONCLUSIONS

This thesis provide a design with guidelines and recommendations for the external fixed shading devices configuration and properties in order to achieved the maximum energy saving potential during the four different seasons in the UAE climate condition. The use of fixed external louvers in building façade achieved a significant reduction in energy saving with different scenario. This study found that the louvers shade with the same ratio in (LW) and (LS) results approximately the same effect in energy saving. The optimum energy saving reduction was recorded by using louvers Aspect Ratio (AR=3.0) with semi-transparent materials and Visible Transmittance (VT) 50% was achieved 33.16% annual average energy saving comparison with the base case (without louvers shading) for the South orientation. The optimum louvers AR configuration was AR=3.0 with annual average percentage of reduction in energy saving 29.33%, 25.06% and 23.47% for the South, East and West orientations, respectively. The study found also that the changing in louvers AR, (LW) and (LS) is more efficient in energy saving than the changing in louvers angles. This study illustrate that the VT value for the semitransparent material has the optimum energy saving in VT 50%. However this VT value allows penetrating the maximum defused sun light and protects the building facade from the direct sun radiation. The study shows the semitransparent material with VT 75% allowing the direct radiation to penetrate inside the building which increases the cooling load demand.

The study found that the annual energy reduction of 33.16% compared with the base case for the South orientation as a maximum annual energy saving during the four seasons. The study found also a slight difference in the annual energy saving for the East and West orientation with 25.06% annual energy saving for the East orientation and 23.47% for the West orientation. The study for the South, East and West orientations shows a very small reduction value of energy saving 0.353% to 0.415% compared with the standard martial color for louvers by changing the louvers color from opaque material to mirror material during the whole year seasons.

REFERENCES

Aboulnaga, M. M., (2005) towards green buildings: Glass as a building element-the use and misuse in the gulf region. Renewable Energy 31 (2006) 631–653.

Al-Sallal. K. (2006). Testing glare in universal space design studios in Al-Ain, UAE desert climate and proposed improvements. Renewable Energy 32 [online]. pp 1033-1044.

Collins. M, Tasnim. S, and Wright. J (2007). Determination of convective heat transfer for fenestration with between-the-louvered shades. International Journal of Heat and Mass Transfer 51 [online]. pp 2742-2751.

Chen, B., Chen. X., Ding. Y. and Jia, X. (2005). Shading effects on the winter thermal performance of the trombe wall air gap: an experimental study in Dalian. Renewable Energy 31 [online]. pp 1961-1971.

Crawley, D., Hand. J., Kummert. M. and Griffith, B. (2005). Contrasting the capabilities of building energy performance simulation programs. Proceeding of ninth international IBPSA conference [online]. pp 15-18.

Chung. W and Hui. Y.(2009). A study of energy efficiency of private office buildings in Hong Kong. Energy and Buildings 41 [online]. pp 696-701.

Freewan. A., Shao. L. and Riffat, S. (2008). Interactions between louvers and ceiling geometry for maximum daylighting performance. Renewable Energy 34 [online]. pp 223-232.

Hammad. F, and Abu-Hijleh. B. (2010). The energy saving potential of using dynamic external louvers in an office building. Energy and Building 42 [online]. pp 1888-1895. Available from: http:// www.sciencedirect.com [Accessed June May 2010].

Koo. S., Yeo. M. and Kim, K. (2009). Automated blind control to maximize the benefits of daylight in buildings. Building and Environment 45 [online]. pp 1508-1520.

Kuhn. T., Herkel. S., Frontini. F., Strachan . P. and Kokogiannakis, G. (2010). Solar control: A general method for modelling of solar gains through complex facades in building simulation programs. Energy and Buildings [online]. pp xxx-xxx.

Lam. M. and Miller, A. (2009). Shading performance of vertical deciduous climbing plant canopy. Building and Environment 45 [online]. pp 81-88.

Lawrence Berkeley National Laboratory, (2007) Commissioning and Verification Procedures for the Automated Roller Shade System at The New York Times Headquarters, New York, USA.

Li, H. W. and Tsang, K.W., (2008) An analysis of daylighting performance for office buildings in Hong Kong. Building and Environment, 43 (2008) 1446–1458.

Palmero-Marrero, A. and Oliveira, A. (2009). Effect of louver shading devices on building energy requirements. Applied Energy 87 [online]. pp 2040-2049.

Sutter, Y., Dumortier. D. and Fontoynont, M. (2006). The use of shading system in VDU task offices. Energy and Buildings 38 [online]. pp 780-789.