Evaluation of the Optimal Solar Shading Devices for Enhancing Daylight Performance of School Building  
A case study of semi arid climate – Erbil city

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Abstract- A well-integrated shading device has a greater positive impact on school building than any other sustainable building strategies. The present research aims to propose and evaluate several architectural shading devices that can be integrated into educational building designs in daylight-illuminated classrooms lit from a single side in semi-arid climates. These elements have a potential in allowing the penetration of natural daylight with improve indoor thermal environment and eventually reduce the energy consumption through cooling and artificial lighting. The final goal of the research is to obtain the optimal parameters (geometry and materials) of shading devices for the simulated orientation of classrooms in the case study.

A computerized simulation tool (IES<VE>) is used to carry out the investigation; taking a typical public school building in Erbil City as the empirical background of the semi-arid climate. A series of simulations are performed to determine the average illuminance value and the uniformity of the illuminance distribution in the classroom under various lighting conditions and orientations without shadings fitted to the window. Then the numerical results are found to be compared with the illumination properties of different shading devices that have been considered.

The results indicate a different optimal shading device in terms of enhancing daylight properties in the classroom. By giving appropriate physical dimensions, various shading devices can achieve the average illuminance requirement of (300-500 lux) and improve the lighting uniformity ratio (0.40–0.42) for east orientation within appropriate material. Correspondingly, by using optimal shading device, the required illuminance ratio of 0.5 can be obtained simply in the classroom, accordingly, reduce the lighting power cost compared with the base-case.

Keywords- Shading device; daylight illumination; glare; thermal comfort; school classroom; semi arid climate; building simulation; IES<VE>

I. INTRODUCTION

A. Motivation

In architecture and other related disciplines, sustainable approaches dramatically demand for reducing energy consumption and improving occupant’s comfort in built environments [1]. In general, lighting, heating and cooling loads require considerable amounts of energy consumption in different types of buildings around the globe. Therefore, to minimize these loads, several factors are needed to be incorporated with such as building exterior form, orientation of a particular façade, openings’ sizes and shapes, window transmittance and solar shading devices.

A well-designed building needs considerations of the daylight and solar issues at early design stages. The early stages in the design process include critical decisions on the orientations, size of openings, building form and materials etc. [2]. Existing buildings can be retrofitted via the application of shading devices to address glare, energy and thermal issues [2].

Daylighting has distinguished benefits comparing to artificial lighting, whereas it is not constantly used as a preferred solution for lighting since daylight often causes glare and heat gain issues [2]. There have been many attempts toward improving daylighting through the use of solar shading devices; however, the majority of these studies focus on office buildings with large windows facades [5,6,7,8,9,10].

According to a study, around 60% of school building’s light usage is artificial light while schools are commonly operated in the sunshine hours. Effective use of daylight results in saving energy, supplying comfort and promoting health and productivity. It also improves classroom learning up to 26% comparing to classrooms with minimum daylight [11].

Although the daylight in Erbil city is virtually sufficient to achieve the required illumination conditions in classrooms without the need of artificial lighting, the literature contains very little information concerning effective methods for guiding the daylight into classrooms, hence incorporating daylight into architectural lighting schemes in order to reduce the energy costs of a building. In general, achieving a uniform illumination distribution within the classroom is essential in protection of the students’ eyesight. Accordingly, the current study investigates the feasibility of using sun-shadings of various configurations as daylight access devices in order to improve the illumination conditions within a typical classroom in Erbil city.

B. Solar Shading Devices for Energy Performance and Daylight Efficiency

Solar shadings are basically mechanical devices or textiles that can be installed either externally, internally or in-between
spaces in any type of buildings. The main objective of the integration of such systems is providing comfortable work places both visually and thermally.

Researchers have proven that the integration of solar shading devices into buildings has many significant advantages in terms of reducing energy consumption and improving daylight quality. Having a full control over sunlight and daylight is possible through implementing of an optimum shading device which results in optimizing passive solar heating in winter and reducing solar gain in summer \[12-13\]. Diffusing and directing natural illumination progress daylight quality approximately in all climates.

Frewen [14] illustrates a matrix of daylight devices which can help designers to choose a most suitable device in a particular space, project and design stage. This system depends on the type of design and lighting needs. The study is useful for a new building design in which the designer encounters problems in the design process. The proposed matrix can be considered as a general guideline for building designers but not accurate enough for a specific weather or location.

Frewen [1] examined the impact of shading devices on reducing heat gain in summer and improving visual environment in south-west facing office building in hot climate (Jordan). Three fixed shading installations “egg crate, diagonal and vertical fins” were used in the study and the results demonstrate that air temperature was reduced via blocking direct sun rays and visual environment was promoted via preventing glare, enhancing uniformity and taking control over illuminance level compared to the offices without external shadings.

Al- Tamimi and Fadzil [15] investigated the capability of external shading devices in maximizing the number of comfortable hours. The results claim that there is, respectively, an improvement in ventilated and unventilated spaces by 4.7% and 26%. According to this study, the egg-crated shading device is the most effective than other types of shadings in reducing the solar heat gain in such weather conditions.

Grynning et al. [16] assessed the influence of solar shadings on energy needs in cold climate offices through examining of multiple shading devices for north and south facades with altering office areas, window sizes and parameters. The results reveal that using shading devices for north façade is not that effective for demand reduction and the potential of occurring glare is very low as Glare Index (GI) does not transcend 12 in this particular facade. Contrary, a novel choice of shading device for south façade reduces energy demand by 9%. Hence, our research will ignore the investigation of north facing façade in the selected school building case study. Also, south facades will be neglected due to the quality of this particular facade as declared in the majority of studies that fixed overhangs perform effectively in south façades when preventing high sun angles in summer and allowing low sun angles in winter to shine windows. Therefore, the concentration of this study will be on east and west facades as these facades require critical design decisions in most cases.

Samanta et al. [3] demonstrated the impact of moveable shading device on energy efficiency in a residential building in a tropical region (India). They argue that the building design and its orientation play a major role in the efficiency of shading device. The simulations illustrate that the dynamic shadings reduce temperature by up to 1.5 °C and cooling loads by 8% compared to the base case.

Dubois [10] stated that external shading devices are more operable by 35% in comparison with interior devices or in between panes due to externally installed shadings prevent solar radiation to reach onto the windows. A shading device has a considerable impact on window U-value. Thereby, it reduces heat loss through windows by 45%-58% when using a metallic coated material. Light-colored shadings are declared to be more influential by 20%-40% comparing to dark-colored ones. This study shows that a low solar transmittance shading devices can reduce cooling loads by 23%-89%.

From the reviewed studies, specifically \[1,12\], the efficiency of solar shading devices can be assessed by considering the following performance indicators:

- Daylight quality (preventing or reducing glare)
- Daylight quantity (maintaining daylight level)
- Air temperature (blocking direct sun light, reducing heat gains and cooling loads)
- Visual impact (providing outside view)
- Users’ interaction (promoting environment)

C. Daylighting – Visual and Thermal Comforts

In general, daylighting has significant benefits for all types of buildings regardless of the different climate conditions. In particular, school classrooms can employ an outstanding daylighting system when controlling daylight in an effective way. In semi-arid climates (i.e. Erbil City) daylighting, if not properly incorporated, causes glare problems and heat gains. In contrast, according to \[11\] daylighting has numerous benefits especially for school classrooms, such as:

- Improving visual tasks in schools since it can perform an optimum light quality
- Reducing artificial lighting costs that operated in schools by 40%-60%
- Saving energy by 20% through decreasing cooling loads
- Minimizing energy peak usages and carbon footprints
- Boosting student performance since an appropriate daylight rises test scores by 20%
- Maintaining connection to nature when daylight alters with outside weather

Glare is a visual perception caused by excessive and uncontrolled light which results in different luminance level between a brightened area and the rest of surrounded surfaces. Daylight glare and visual comfort are generally evaluated through quantified glare index (GI) and illuminance level (lux). The discomfort glare index (DGI) is concerned to various levels of GI where human sensation of glare involves
on diverse styles in which reduction in work performance is most significant form. According to the software manual of EnergyPlus 2012 and European standards of lighting, the BI borderline between comfort and discomfort is set at 22, also 20 stated as acceptable and 24 as uncomfortable [16].

An efficient daylight illumination leads to reducing the use of artificial light, demanding for cooling loads and improving work performance. An appropriate illuminance level, as suggested in most lighting standards, is between 300-500 lux or higher. Thus, our research will assess the integrated shading devices based on glare indexes 20 and a maintained illuminance level of 500 lux.

Konstantzos et al. [6] studied the evaluation of daylight glare probability in office work areas with advanced roller shading device. This experimental and simulation study was an attempt to overcome glare issues and the results demonstrate that this technique is capable to prevent glare with maintaining acceptable interior illuminance level. Having an efficient control over vertical illuminance fulfills visual comfort via reducing glare. Authors suggest an appropriate balance among visual comfort, energy consumption and outside view.

A prediction method of a simulation-based model for daylighting configuration design is proposed to help designers in the process of choosing “optimal window dimensions and position, glazing transmittance and blind reflectance” in which reducing calculation and simulation time consuming dramatically [17]. However, as authors stated, this prediction method has a few limitations, for instance in the validation procedure the number of window choices were restricted and the glare was not calculated.

A number of studies have recommended that daylight quality can be assessed by considering several performance indicators. According to [4-9] the major indicators are:

- Daylight factor
- Absolute luminance in the level of view
- Illuminance of the work place
- Luminance ratios between the walls and work plane
- Illuminance Uniformity on the work plane

### II. Methodology

#### A. The Case study

Erbil city I located in the north of Iraq between latitudes 35°30’ and 37°15’ N and longitudes 43°22’ and 45°05’ E. The climate in Erbil can be characterized by extreme conditions with seasonal temperature variations between day and night. The summer season is between June and September with hot and dry weather. July and August are the hottest months, when dry bulb temperature ranges from 42-43°C. In hot weather the outside dry temperature may exceed 50°C during the day while it drops sharply to 30°C during the night. The winter season is mild/wet, with temperature ranging from 12–14°C and the low mean temperature is 2–7°C, with an annual rainfall of 375–724mm as shown in “Table I”. The average direct sun component is generally about nine hours a day.

The base case school building for this research is the prototype of schools in Erbil city and some of other areas surrounding, which have been built by local companies considering the local standards of building construction. Mawlawy school (latitude 36.1N, longitude 44E), in Tairawa district is one of the prototype Schools in Erbil city. The building was constructed with un-insulated external concrete block wall 24 cm. A 12mm thickness glass has been assumed to be the single glazing for the school, with the same glazing were used for roof light of reception and the original exciting block wall. Simply un-insulated construction was added to the roof which is consisting of a layer of cast concrete and slate tiles. Floor with un-insulated cast concrete were assumed for the building “Fig. 1”. The building consists of three floor plans.

The plans of the class rooms are divided into two wings, where each wing has a double loaded corridor with three classes at each side. Ground and first floors are being devoted for class rooms only, where third floor has 3 classes only with nine other classes for music, drawing, computer and laboratories classes. The total area of each class is 48 m², with dimensions of (8.0 x 5.10 m) “Fig. 2”. The façade height is 4m in each floor as 0.80m sills, 2.00 m height of the window.

#### Table I. Average Annual Temperatures and Sunshine Hours

<table>
<thead>
<tr>
<th>Month</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg Temp</td>
<td>12</td>
<td>15</td>
<td>19</td>
<td>25</td>
<td>32</td>
<td>39</td>
<td>43</td>
<td>42</td>
<td>38</td>
<td>29</td>
<td>21</td>
<td>14</td>
</tr>
<tr>
<td>Avg Min Temp</td>
<td>2</td>
<td>3</td>
<td>7</td>
<td>11</td>
<td>16</td>
<td>21</td>
<td>25</td>
<td>24</td>
<td>19</td>
<td>14</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Avg Sunhine/Day</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>10</td>
<td>14</td>
<td>14</td>
<td>13</td>
<td>11</td>
<td>8</td>
<td>6</td>
<td>5</td>
</tr>
</tbody>
</table>

**Figure 1.** The case study prototype school
The tested classes were taken from four orientations (North, South, East and west), as the classes in all these orientations are exposed to the direct sunlight which produce glare and excessive heat gain with solar radiation. There are different considerations need to be taken for each orientation in order to control solar gain in summer, heat lose in winter and undesirable glare in the class “Fig. 3”.

Windows not only have a significant impact on energy consumption but also create healthier learning environments that may result in increased attendance and improved grades. The characteristics of the windows and their location, design, and purpose will determine, to a great degree, the level of energy efficiency the school achieves and helps to provide adequate illuminance for visual tasks. The current study investigates the performance of three main types of static shading devices and to find out the optimum shading devices configuration for east classroom orientation. The main aims of designing shading devices is to control the direct exposed class the sunlight and enhancing the daylight performance in the class in order to prevents glare and excessive heat gain.

According to Mardaljevic [18], Climate-based daylight modeling (CBDM) is the prediction of various radiant or luminous quantities (e.g. irradiance, illuminance, radiance and luminance) using sun and sky conditions that are derived from standard meteorological datasets. Modeling depends on the location of the building (such as the climate data that was used geographically), building orientation (such as illumination of the sun and overcast sky conditions that were included) and building composition. Based on the studies by Mardaljevic and Cannon-Brookes [19,20] CBDM has been demonstrated using only computer simulation techniques. Thus, the same method were used for this study.

For the purpose of investigating the effects of external shading devices on indoor environment, the present study used computer modeling techniques (IES-VE) which have been widely promoted as an effective and reliable tool to optimize the design process for buildings. However, in order to carry out successful computerized building simulations, accurate and reasonable input data for the buildings and climate are essential [21]. Therefore, to enhance the accuracy there is a need to compare the result with measured data and input parameters that effect the simulation process, this procedure called (calibration of the simulation model).

To calibrate the building simulation, IES<VE> simulation results were compared with fieldwork data. The methodology divided into three phases. The first phase was the data collection from the field then followed by the verification and validation process, which included a model of the chosen school building and the existing external shading device and run the base case simulation. The second stage involved simulating of the three types of proposed static shading devices model.

The model for the whole building was simulated in order to evaluate the windows’ performances for each orientation. As shown, all the classes were lit to direct sun light from one side only. The following figures indicate the actual performance of each orientation.
Figure 5. Solar Shading Calculations Shows the Solar Attitudes through the Year, the Selected Zones Refer to the Number of Hours/Month which the School Operates

Figure 6. Daylight Factor for Ground Floor

Figure 7. Daylight Factor for First Floor

Figure 8. Daylight Factor for Second Floor

From running the daylight simulation for the classrooms in each orientation the results were as following:

The base case indicates that a transparent east-south-west facing classrooms skin without shading devices are fully exposed to the direct sunlight which affect both comfortable visual and thermal environments of the classrooms. According to CBSE guide [22] the maximum allowable illuminance level for class is between 300-500 lux “table II”, while it can be seen that it is over 800 LUX nearly 30% percent of the floor area at 1:00 pm. Erbil city is classified as semi-arid hot climate the indoor temperature exceeds the desired temperature for the extended period, the whole summer. North direction has no much sun lit into the class in which the illuminance is within the limited range, the lit-in sunlight into this orientation is desirable. Therefore, the north oriented class was excluded from this research. While south oriented classroom has the best performance in term of the solar radiation during the summer time it’s also been excluded from the study. West orientation is considered as the worst orientation due to the excessive solar gain during the evening time therefore it’s been classified to be out of the research scope due to the study hours of the school. The study hours start from 8:30 AM till 1:30 PM and in some private school
till 3:00 PM; therefore, east orientation has been measured and tested as the scope for this research.

**TABLE II CBSE CODE FOR LIGHTING**

<table>
<thead>
<tr>
<th>Education Area</th>
<th>Illuminance (lux)</th>
<th>Limiting Glare rating</th>
<th>Uniformity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classrooms and tutorial rooms</td>
<td>300</td>
<td>19</td>
<td>0.60</td>
</tr>
<tr>
<td>Classroom for evening classes and adult education</td>
<td>500</td>
<td>19</td>
<td>0.60</td>
</tr>
</tbody>
</table>

The same as criteria of IES standards call for an illuminance of 300lux to 500lux for a typical classroom. According to the CBSE guide the important design criteria for classrooms include the flowing:

- Daylighting integration,
- Glare
- Luminance of room surfaces,
- Uniformity of light distribution.

These criteria may discount tasks such as reading which is one of the most important activity and art projects that occur in classrooms for lower grade levels. This study has been conducted to compare the performance of different shading structures for east orientation with regard to the criteria of design guideline for the class room by CBSE. In order to have a realistic comparison of shading devices, daylight factor, glare and Luminance of the room surface have been taken into account.

**C. Types of Shading Devices**

There are many types of external shading devices, though the most common types are vertical and horizontal shading devices. The design of shading devices depends on variety of different variables, which lead to the need for specialized design for each location or orientation. For the climate of Erbil city, in summer the interior has to be completely protected from direct sunlight. When the dry-bulb temperature is above comfort level (40-48) the solar radiation will heat up the indoor space that has been cooled down, thus increasing the energy consumption for cooling load. On the other hand, in winter, the room needs to be heated up by taking the advantages of direct sunlit in order to decrease the amount of energy demand by heating. The following types of conventional shading devices were examined and tested on east orientations for Erbil city (see Appendix A):

- a) Horizontal louvers
- b) Vertical louvers
- c) Egg-crate shading structures*

- a) Horizontal louvers

The type of horizontal louvers that is tested in this study consists of blinds that are perpendicular to the surface. They span over the whole width of the window with depth (25mm), different a distance between each blind. Although It is assumed that horizontal shading devices perform generally best in south for Erbil city, it has been tested on east orientations to evaluate its performance.

- b) Vertical fins

Vertical blinds can be optimized in depth and height. If the height is greater than the opening, they can only have a very limited effect on the reduction of solar rays on the surface.

- c) Egg-crate

Egg-crate shading structures are tested with a square opening, a horizontally (1:4 - 1/2':2') and a vertically oriented opening (3:1 - 1 1/2':1/2').

**III. RESULTS AND DISCUSSION**

The analysis of the results of the effect of the external shading devices on daylighting performance is conducted by comparing the base case model with alteration of shading devices. East has its peak in the summer around Jun and July, when the sun is at a position more perpendicular to the surface and at a very high azimuth angle. Thus, the sun rises at early morning which causes a large light intensity in the classrooms.

**A. Base case Results**

“Table III” indicates the daylighting performance results of the existing base case in the school east façade during the peak summer. The existing case study shows that the average level of illuminance in the classroom was very high as ranging from (470.40 lux at 10:00 am - 658 lux at 11:00 am) during July. Moreover, the average percentage of area where the illuminance is exceeding the thresholds 500 lux was calculated (36 %). Beside that the uniformity of the daylight or distribution of the light is quite low (0.56) and low daylight diversity (0.07) in overall. Moreover, the vertical surfaces receive low ration of the daylight ratio with percentage of 45% less than 300lux at 11:00 AM in July.

<table>
<thead>
<tr>
<th>Time</th>
<th>Illuminance Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:00AM</td>
<td>470.65lux</td>
</tr>
<tr>
<td>11:00AM</td>
<td>658.42 lux</td>
</tr>
<tr>
<td>1:30PM</td>
<td>578.02 lux</td>
</tr>
<tr>
<td>3:00AM</td>
<td>530.46 lux</td>
</tr>
</tbody>
</table>

**TABLE III AVERAGE ILLUMINANCE LEVEL ON THE WORK PLANE (BASE CASE MODEL)**

The average daylight factor estimated 3.13 DF for the base case in July while estimate as 3 DF in May. Though the area which that exceed the threshold level of the daylight factor (2DF-5DF) are more than 20% each time “Table IV”
TABLE IV DAYLIGHT FACTOR BASE CASE

<table>
<thead>
<tr>
<th>Date</th>
<th>Daylight Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 June</td>
<td>25% &gt; 500lux</td>
</tr>
<tr>
<td>21 July</td>
<td>22% &gt; 500lux</td>
</tr>
<tr>
<td>21 May</td>
<td>20% &gt; 500lux</td>
</tr>
</tbody>
</table>

This was because the external window faces east and receives high amount of the direct daylight during the whole mooring till late afternoon during the summer period. Thus, the tested classrooms did not show the potential of daylight utilization as it causes large cooling load (5.8 MWh – Total Yearly Energy Consumption for cooling and artificial lighting) for one classroom due to high reading of the indoor air temperature “Fig. 10”.

The glare problem caused by extremely uneven daylight distribution close to the façade and create spots without sufficient lighting. The visual comfort of the human [23] requires adequate illuminance level with controlled glare. Glare Problem is analyzed by taking into consideration glare index and Visual comfort probability (%) of people who would be satisfied. IES calculate the glare index by analyzed glare angles which are +60 to -60 degree in steps of 10 degrees. This study adopts IES code for classrooms and college as daylight glare index 21. The glare index for the base case classroom shows low glare index due to large luminance level in the room.

![Figure 10. Indoor Air Temperature (Basecase).](image)

The effect on light distribution images it is clear that the vertically oriented type delivers the best amount of shading performance with better than the square and better than the Horizontally oriented type. Generally, all the three type of Egg crate shading devices admit illuminance lower than the recommended level between (80 lux at the afternoon for the square type -180 lux at 12 PM for the vertically oriented. It can be seen that the Vertically Oriented Egg crate has achieved the best performance in compare to the other type of the Egg crate as it admits illuminance with accepted range between (120-180lux). It can be seen that the (Shad.SE) admits illuminance 18% higher than (Shad.VE) and 17% higher than (Shad. HE). Both (Shad. SE) and (Shad. HE) have conducted similar results with slight higher performance for the horizontally oriented 9% at 10 am.

b) The effect on light distribution

The illuminance contours’ images show the distribution of the illuminance on the horizontal work planes in the tested classroom (See Appendix B). From all the images it is clear that the three types of shading devices prevent direct sun light 100% and diffuse light 55%. The horizontally oriented type delivers the best amount of shading for east orientation with 13% more than vertically oriented and 7% more shading than the square egg crate shading devices. These results come along with a study conducted by Bader [24] to get most effective egg crate shading structure width has to be greater than the height. The illuminance level pictures show that the egg crate devices protect the inner surfaces from direct sunlight and disturb the light in the classroom. The Horizental egg crate reduce the area that exceed the threshold level of the illuminance 500 lux into less than 5% only while increase the percentage of the area within average 300 lux by 7% in compare with base case. Therefore, the horizontally oriented egg crate has the potential to reduce the total energy demand for cooling into 5.4 MWh which is nearly 7% reduction of the totally yearly energy consumption for the classroom. There was slight reduction in the energy consumption by cooling load when using vertical and square

![Figure 12 Average Illuminance (Lux) on Horizontal Work](image)
c) Solar radiation and shading coefficient

In order to be able to compare the shading structures to each other, a coefficient has to be introduced - the shading coefficient ‘sc’. It represents the ratio of the amount of solar radiation between an unobstructed and an obstructed surface. A sc of 0 would not allow any solar radiation at all on the surface. An sc of 1.0 is basically an unobstructed surface, which receives full solar radiation. Besides that, it is essential to know how the different orientations compare to each other with regard to the respective annual solar radiation on the surface. The Simulation process evaluates the solar radiation per each month for all the shading devices “Fig. 13 & 14”.

Figure 13. Monthly Solar Radiation of Egg-Crate Shading Devices

![Chart showing monthly solar radiation for different orientations of shading devices.](chart)

Figure 14. Annual Solar Gain

According to the Annual solar gain the horizontal Egg crate has achieved the lowest (sc) of 0.50 therefore the more shading is provided for the classroom. While The square egg crate achieved 0.51sc and 0.55sc for the vertically oriented. This is due to the high solar radiation received by the (Vo shad.) on the inside vertical surfaces specially during May and July with 247kWh/m², 230 kWh/m². The vertical surfaces inside the classrooms within (Ho shad.) received the lower solar radiation during the summer period 200kWh/m², 180kWh/m² during Jan and May respectively. The square egg crate achieved the second better results. Thus, egg crate devices protect the inner surface and windows from the direct exposure to the solar radiation, especially during the morning and early afternoon before 4 pm. The lower solar radiation results to lower indoor air temperature and also reduce the heat gained in the space.

Generally, egg crate shading structures always perform best than other type of the shading devices as it shown the sections below. Yet, to provide maximum shading might not always be the desired goal since the degree of visual contact from the interior might suffer. The degree of the visual contact is an index of the level of the visual comfort of the people inside the room degree of visual contact calculated by (%)(A (opening)) / (A (area of shading structure)). The more shade, the more obstruction, the lower the degree of visual contact. The results were 85% for (So Shad.), 76% for (Ho Shad.) and 75% (Vo. Shad.). Nevertheless, to provide shading already resolves in a minimum reduction of solar radiation of almost (53% by the Ho Shad.). This will result in a reduction of heat gain and thus a reduction of energy consumption, which is the final goal.

2) Horizontal shading device

a) The effect on Light intensity

The results of the alternatives of shading devices where compared with base case horizontal louver which is originally exist in the building. Four different alternatives where proposed according to the sun path diagram. The effect of the horizontal shading devices on the illuminance level and light distribution in the room presented in “Fig. 15”

![Chart showing annual solar gain for different alternatives.](chart)

Figure 15. The Effect of the Different Horizontal Shading Devices on the Indoor Illuminance

The results show that all the types of the horizontal shading devices are accepted to be apply on the east façade except the fourth type (IV) which has reduced the illuminance in the room under the thresholds level with 45% of the area under 300lux at 3:00 pm, while at the morning the
average level of illuminance reduced into less than 100 lux over 90% of the total area. Therefore, this type is neglected as it also reduces the daylight factor into less than 0.5DF. The best results were introduced by the horizontal louver (I) which it has maintain the illuminance level with the required level during the school time. The results by type (I) was between 476.48 lux at 11:00 am and 328.24 lux at 3:00 pm. It also reduces the percentage of the area that was exceed 500lux into 24.75%, which is a 35% reduction of the area in compare with base case. The other types (II) and (III) admit illuminance under the threshold of 300lux with slight better performance for the type (II) 8% higher than type (III), especially during the mooring time or before 3:00pm. Base case horizontal louver has achieved the second best result after the first type with illuminance ranging from (332 lux at 10:00am – 219lux at 3:00pm). Base case horizontal shading device is 9% higher illuminance distortion than type (II) and 15% than type (III). however, type (II) are more effective during the evening time.

b) The effect on light distribution

The distribution of the illuminance on the horizontal work planes in the tested classroom for the base case and the proposed horizontal shading devices were simulated (See appendix C). The results indicate that horizontal shading device type (II) has conduct best shading percentage 42% over the total area which is 7% higher than the overhang and 25% than type (I). Both types (III) and (IV) could reach to more than 89% shading the classrooms; however, this amount can block the sunrays up to 80%. Although last two types of the horizontal shading devices achieved high percentage of room shading they are un desirable as they can block the view and cause un pleasant visual comfort. The degree of visual contact reaches (98.20 %). Overhang (original base case) and type (I) have only (25%, 30%) respectively. Therefore, overhang and horizontal shading device type (I) considered as the best types among the rest of the horizontal types as they provide both good daylight distribution and accepted percentage of shading area. These results are agreed with study [24] which indicates that the overhangs have their strengths in allowing the user to have almost unobstructed visual contact with the exterior.

c) C.3 Solar radiation and shading coefficient

“Fig. 16 & 17” show the amount of solar radiation per month for each alternative in compare with base case overhang.

As shown in the “Fig. 16” the horizontal louveres type I received the most average solar radiation thought the year. Its maximum solar radiation on Jun with 255 kWh/m². While, case II and the overhang received nearly same amount of solar radiation through the year. Case IV received the least amount of solar radiation which increased the shaded area.

According to annual solar gain case IV score the lowest sc (0.47) while case I is the highest amount sc 0.76%. Rest of the cases has nearly the same value for sc 0.64. Thus, Overhang are highly efficient when the sun is at high positions. But, as the sun gets lower, the wider the shading device has to be to provide sufficient shading. Some overhangs are designed to reflect direct sunlight into the depth of the room. This helps to reduce artificial lighting while providing natural daylight. Generally, horizontal shading is highly effective against direct sunlight from a high angle. Due to their operability, horizontal fins are usually very effective. They can almost provide full shading according to the requirements of the occupant or depending on the position of the sun (orientation of the building or time during the day).
3) Vertical shading device

a) The effect on Light intensity and distribution

Five different alternatives of vertical fins were simulated in order to be evaluated and compared with base case vertical Fin that originally designed for the school building. “Fig. 18” shows the average illuminance distribution on the horizontal work plane for all cases. The results show that the average illuminance in the base case is high during afternoon in which nearly 30% of the total area exceed the thresholds of 500lux. This indicate un comfortable thermal condition in the classroom 37% of the occupants shows visual comfort probability. The glare index for the base case vertical fins is over 24 and the Glare thresholds 519.76 cd/m². Most of the proposed cases shows improvement in the illuminance level and light distribution in classroom except vertical fins type (III) which provide large shading area cause to reduce the area into 68.55% of total area below the thresholds level of 300lux.

The best results were performed by type (IV) with average (340lux at 1:30 pm. -300lux at 10 am) and 43% of the occupants shows visual comfort probability followed by type VI and type I with average (354lux, 392 lux at 1:30 pm respectively).

Illuminance distribution image (see appendix D) the results indicate that vertical Fins IV has conduct best shading percentage 32% over the total area for the east oriented classrooms 11% higher than case VI and 8% higher than case I. The degree of visual contact reaches to nearly (83%) for both case II and VI while its lower in the case IV 70% and nearly 75% for both Case VI and I.

b) Solar radiation and shading coefficient

Vertical shading is very effective for direct sunlight at a low angle, such as during the morning, the afternoon and the evening. “Fig. 19” shows monthly solar radiation for each case. Base case received the most average solar radiation thought the year. Its maximum solar radiation on May with 350 kWh/m². While case II and the VI received nearly same amount of solar radiation through the year. Case III received the least amount of solar radiation which increased the shaded area, its maximum solar radiation Jun 210 kWh/m². The total radiation in decrease for each case according to the sc.

Figure 19. Monthly Solar Radiation of the Vertical Fins

According to annual solar gain case III score the lowest sc (0.43) while case I is the highest amount sc 0.64%. Vertical fins generally block low solar radiation coming from the side. Thus, they are useful on east facing façades. Therefore, even if the outside view is limited due to the vertical shadings, similar to horizontal shadings, most of the window is protected from direct sunlight. Vertical fins are generally not successful when the solar altitude angle is too high during the hot season. For these orientations a combination of vertical and horizontal fins is most effective at blocking the sun for both, high and low positions.

IV. CONCLUSION

This paper has presented empirical study of daylighting performance for external shading devices. Three type of conventional shading devices were proposed. Each type has several cases where parameters are change according to the need time for shading. The study examined the effect of these
alternatives on three parameters: Light intensity and distribution, Solar radiation and solar gain and relation with visual contact. Providing comfortable daylighting conditions will lead to reduce the uses of Electrical lighting and on the demand for cooling load in overall.

This qualitative research has been conducted in order to gain the necessary knowledge to design an optimized shading system. An optimized shading system represents a structure that provides maximum shading for a specified period throughout the year while allowing maximum solar exposure for another period. To be able to do so, a study of a typology of existing conventional shading systems were conducted. Knowing about existing shading solutions helps to define the needs and requirements of an innovative optimized shading structure. To optimize conventional shading systems, the process of designing such systems had to be analyzed

The study has come with the flowing conclusion:

- If a shading structure provides full shading throughout the year, it might fail to provide a high comfort level for the user. A high amount of provided shading might lead to a low degree of visual contact. The ultimate shading device provides maximum amount of shading with a maximum degree of visual contact. The tests that have been conducted so far treated the shading components as simple 2-dimensional surfaces. Horizontal and vertical blinds may provide the highest degree of visual contact for a uniform material thickness, but they don’t perform as well in providing shading. On the other hand, egg crate structures provide the most shading, but they have a lower degree of visual contact for the same thickness. Vertical Fins (IV) and Vertical (VI) shading structures perform best in providing shading and have a higher degree of visual contact flowed by horizontal Shading devices than egg crate shading structures devices with a similar material thickness. On the other hand, egg crate structures provide the most shading, but they have a lower degree of visual contact for the same thickness.

- All egg crate shading structures, perform best on East in terms of shading percentage during the summer period. Yet, the horizontally oriented type provides the highest amount of shading SC 0.40, but they have a lower degree of visual contact for the same thickness. flowed by horizontal oriented egg crate 0.5. Horizontal shading devices achieved shading performance with SC 0.47 for case IV, while other horizontal louvers achieved an average SC 0.76. vertical shading devices case (III) score the lowest SC (0.43) while case I is the highest amount sc 0.64%. Vertical fins generally block low solar radiation coming from the side.

- The Horizontally oriented egg crate has the potential into reduce the total energy demand for cooling into 5.4 MWh which is nearly 7% reduction of the totally yearly energy consumption for the classroom.

- In the early morning as well as late afternoon, vertical blinds are very effective since the angle between the azimuth angle of the sun and the normal vector of the opening is very high. As soon as the sun rises in the morning and the altitude angle of the sun gets higher, the less shading can be provided by vertical blinds. To optimize vertical blinds, they should be operable so that they can be positioned perpendicular to the sun at all time to provide maximum shading.

REFERENCES


### Appendix A: Design and Details of Shading Devices

<table>
<thead>
<tr>
<th>3D View</th>
<th>Type</th>
<th>Distance between blind</th>
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<tbody>
<tr>
<td><img src="image1" alt="Basecase without shading devices" /></td>
<td>Basecase without shading devices</td>
<td>Lift and right</td>
</tr>
<tr>
<td><img src="image2" alt="Basecase with original vertical fins" /></td>
<td>Basecase with original vertical fins</td>
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</tr>
<tr>
<td><img src="image3" alt="Basecase with original horizontal louver" /></td>
<td>Basecase with original horizontal louver</td>
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<tr>
<td><img src="image4" alt="Horizontal louvers (I)" /></td>
<td>Horizontal louvers (I)</td>
<td>Top and bottom</td>
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<td><img src="image5" alt="Horizontal louvers (II)" /></td>
<td>Horizontal louvers (II)</td>
<td>Top, bottom and in the middle (1 m)</td>
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<td>Horizontal louvers (III)</td>
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<td><img src="image7" alt="Horizontal louvers (IV)" /></td>
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<td>Vertical fins (I)</td>
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<td>Vertical fins (II)</td>
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<td><img src="image10" alt="Vertical fins (III)" /></td>
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<td><img src="image11" alt="Vertical fins (IV)" /></td>
<td>Vertical fins (IV) at 60°</td>
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<td>Vertical fins (V) at 45°</td>
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<td><img src="image13" alt="Eggcrate square opening" /></td>
<td>Eggcrate square opening</td>
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<td>![Vertically oriented opening (3:1 - 1/2':1/2')]](image14)</td>
<td>Vertically oriented opening (3:1 - 1/2':1/2')]</td>
<td>35 cm, 70 cm</td>
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<tr>
<td><img src="image15" alt="Horizontally (1:4 - 1/2':2') oriented opening" /></td>
<td>Horizontally (1:4 - 1/2':2') oriented opening</td>
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APPENDIX (B) ILLUMINANCE CONTOUR ON HORIZONTAL WORK PLANES

<table>
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<tr>
<th>Time</th>
<th>Egg crate Square Opening</th>
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<td>3:00 PM</td>
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APPENDIX (C1) THE EFFECT OF EACH SHADING DEVICES ON THE ILLUMINANCE OF THE ROOMS

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<th>Basecase model</th>
<th>Original Horizontal Lover</th>
<th>Horizontal Lover (I)</th>
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<th>Horizontal Lover (III)</th>
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## APPENDIX (C2)

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## APPENDIX (D)

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