PLEA 2017 EDINBURGH

Design to Thrive

USING SOLAR SCREENS IN SCHOOL CLASSROOMS IN HOT ARID AREAS: THE EFFECT OF DIFFERENT ASPECT RATIOS ON DAYLIGHTING LEVELS

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Abstract: Hot arid areas are endowed with an abundance of clear skies. Thus, the solar energy available can significantly raise the temperature of interior spaces and also result in an uncomfortable visual environment. External perforated solar screens have been used to control solar penetration through windows. Such screens can also serve a social function, that of maintaining privacy. This paper focuses on a special case of girls' schools in Saudi Arabia, where the privacy issue is critical due to socio-cultural and religious beliefs. Windows in girls' schools facing public spaces are typically covered by dark opaque film to maintain privacy. This window treatment results in overreliance on artificial lighting, and in a corresponding increase in energy use. The performance of screens can be affected by many parameters, namely: perforation rate, depth ratio, shape, reflectivity of colour, aspect ratio of openings. This paper looks at how different Aspect ratios affect the performance of screens by simulating a range of cases of different aspect ratios, using the Daylight Dynamic Performance Metrics approach (DDPM). Results recommend using 1:1 aspect ratio for the south orientation whereas using different aspect ratios for the North and West orientations provide better daylight levels in the studied context.

Keywords: Daylight, Perforated Solar Screens, Schools, windows, Daylight Dynamic Performance Metrics.

Introduction

Areas with hot arid desert climate are characterised by an abundance of clear skies. Thus, the available solar radiation can significantly increase the temperature of interior spaces and result in uncomfortable visual environments due to discomfort glare and poor uniformity ratios (Julian, 2006). Fixed external solar screens can control solar penetration in spaces whilst improve the visual and thermal comfort of the users of such spaces (Harris, 2006). These screens follow the general principles of a shading device that has been traditionally used in hot arid areas, called "Mashrabiya". The Mashrabiya has always had a social function to serve, that of maintaining privacy which is of importance to the Islamic cultures (Fathy, 1986). This dual purpose, explains the widespread use of these devices around the world wherever Muslims exist, from Moorish Spain in the West through North Africa and the Middle East to India in the East (Alitany, 2014). The same principle is used in contemporary architecture to shade facades. Using such perforated solar screens is also proven to reduce energy consumption (Sabry et al, 2014).

The issue of providing privacy for women is significant in Saudi Arabia as the country follows an Islamic regulation, which dictates that women should be covered in the attendance of unrelated men. Following the same regulation, women have to wear "Abaya", a dark robe which they can only take off when inside their houses or in buildings occupied only by women, such as girls' schools. To maintain privacy in girls' schools, it is common for windows to be completely covered by black opaque coatings or non-transparent curtains. Figure 1 shows an example of current situation from a site visit by the main author (Kotbi and Ampatzi 2015).

Figure 1: an example chowing using black opaque film to cover windows

It is well known that such treatments could affect the occupants' wellbeing and productivity, especially students in schools (Erwin, Heschong, 2002), due to the lack of access to external views and adequate natural light (Webb, 2006). These window treatments require exclusive use of artificial lighting, and as a result, girls' schools in Saudi Arabia became significant energy consumers, considering also the numbers of schools and the fact that they all operate during peak hours (Abanomi, Jones, 2005). Considering the characteristics and function of perforated solar screens, it is likely that they are an effective alternative solution to the window treatments currently in place in girls' schools in Saudi Arabia. This research focuses on adopting such screens as a retrofit strategy for existing buildings used as schools, therefore, other solutions that could be effectively integrated in the design process were not considered, such as organising teaching spaces around internal courtyards.

The performance of perforated solar screen can be controlled by different parameters, previous studies have summarized the key parameters affecting the performance of perforated solar screens to: perforation rate, depth ratio, cell shape, colour reflectance, aspect ratio of openings, tilt and rotation angles. The authors have already investigated the effect of perforation rate on daylighting in the same context (Kotbi and Ampatzi 2016), Sherif et al. (2012) also studied the perforation rate in residential living rooms. Aljofi (2005) have looked at the effect of the cell shape and colour reflectance of the screen on daylight distribution in a general context. The latter study concluded that a light colour and a rectangular shape result to improved daylight distribution in comparison to darker materials or round openings. In the context of a residential living room, Sherif et al. (2012) have examined the effect of depth ratio its effect on energy consumption for cooling, heating and lighting , Sabry et al. (2011) have studied the effect of screen rotation angle on daylight . Regarding aspect ratios, Sherif et al. (2013) have investigated the effect of opening aspect ratios on daylighting and on energy consumption for residential living rooms. However, no previous research known to the authors have investigated the effect of aspect ratio on the daylight performance in classrooms.

Objective

This paper is a part of ongoing research that examines the parametric design of perforated screens for both enhancing interior daylight levels and maintaining privacy in typical girls' classrooms in a hot arid area. The objective of this paper is to examine optimum aspect ratios for perforated solar screens to enhance daylighting inside classrooms in hot arid areas for the four main orientations (North, South, East and West). This perspective is considered to be novel, as no other research focusing on this aspect and context is known to the authors.

Methodology

A validated virtual simulation approach is used for this experiment. A 3D base-case classroom was modelled, representing a typical classroom with five windows. This typology is based on a physical survey conducted previously by the authors for 11 classrooms (Kotbi and Ampatzi 2015). In this study, nine perforated solar screens each with different aspect ratio are modelled. In a previous study the optimum perforation rate for solar screens for the same context has been studied (Kotbi and Ampatzi 2016), hence the recommended perforation rate for each orientation is used here. The depth ratio used for each orientation is set according to an optimisation exercise conducted as part of the overall research (unpublished at the time of writing). Other parameters were fixed to control the result. All fixed parameters are listed in Table 1.

The aspect ratio is defined as the ratio between the horizontal width (H) and vertical length (V) of the cell H:V. Screens with four aspect ratios with horizontal direction (2:1, 4:1, 6:1, 12:1) and four with vertical direction 1:2, 1:4, 1:10, 1:20 are examined and compared with a 1:1 square cell. A 6 cm module cell size was used as the basis for creating screens with different aspect ratios. Figure 2 shows examples of different cases.

Table 1: Parameters of simulated solar screens

Module size for cells	6 x 6cm	Depth Ratio	0.15 North, West; 0.6 South; 0.75 East
Colour reflectance	70%	Perforation rate	90% North, West, South ; 80% East

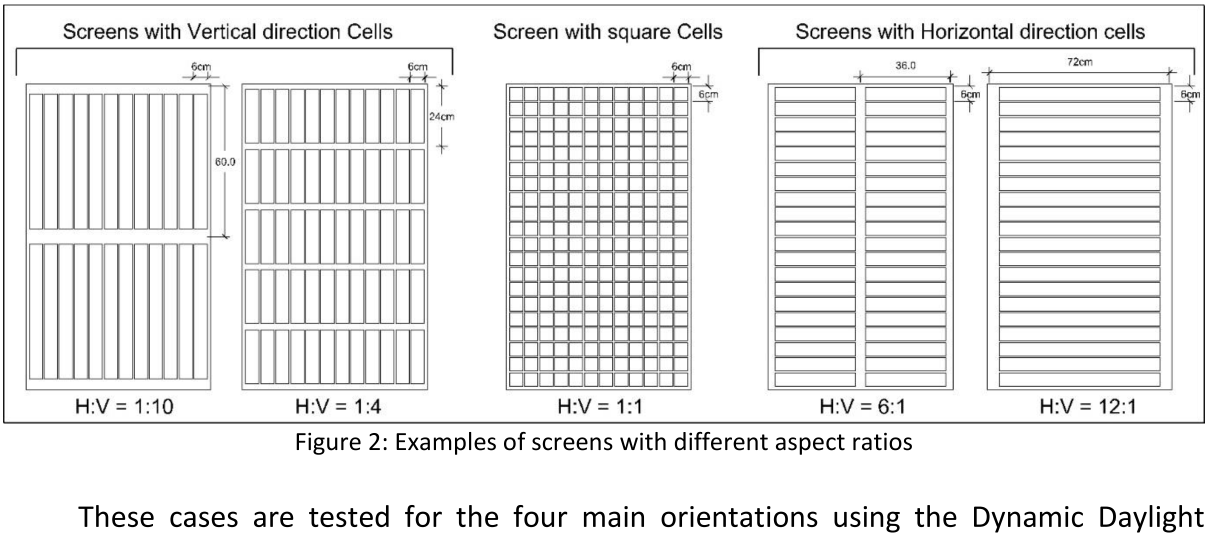


Figure 2: Examples of screens with different aspect ratios

These cases are tested for the four main orientations using the Dynamic Daylight Performance Metrics (DDPMs). These metrics evaluate daylighting performance based on a time series of illuminance levels within a space. The time series cover the occupancy schedule in a calendar year, and based on annual solar radiation data included in the weather data file used in the simulation (Reinhart et al, 2006). The DDPM includes many metrics such as Daylight Autonomy (DA), useful Daylight Illuminance (UDI) and Daylight Availability (DAv). The

DA represents the percentage of occupied hours of the year when at least the minimum required illuminance is achieved; following from that, the space is divided as either 'Daylit' and 'Partly lit' area. Daylit is characterised as the area that has achieved the required illuminance level for at least half of the occupancy hours, while Partly lit area is the area that did not achieve that illuminance level (Reinhart, Walkenhorst, 2001). The UDI uses the lower and upper thresholds of 100lx and 2000lx accordingly to determine illuminance within a useful range, UDI also represents area with oversupply of daylight (more than 2000lx) (Nabil, Mardaljevic, 2006). The problem with the DA is that it does not account for the area with oversupply of daylight in the results, which is usually accompanied with visual and thermal discomfort especially in such climate. "DAv" however, combines both "DA" and "UDI". When using Daylight Availability metric, the space is divided into three categories: 'Daylit' area, 'Partly lit' area and 'Overlit' area, which is the area receiving more than ten times the required illuminance for at least 5% of the occupancy hours (Reinhart, Wienold, 2011). The 5% criterion was selected according to British Standards (BSI, 2007).

Architectural parameters

The dimensions of the base case classroom are 6.90m x 4.50m Figure 3. The dimensions of each of the windows are 0.72m x 1.2m Figure 4. The assumed indoor parameters and reflectance values are presented in Table2. Most schools in Riyadh are surrounded by four streets at least 20m wide and all classrooms are not in a ground floor, hence external obstructions are ignored in these simulations.

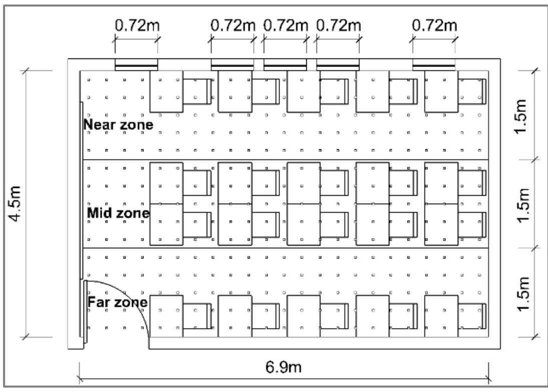


Figure 3: plan of the simulated classroom

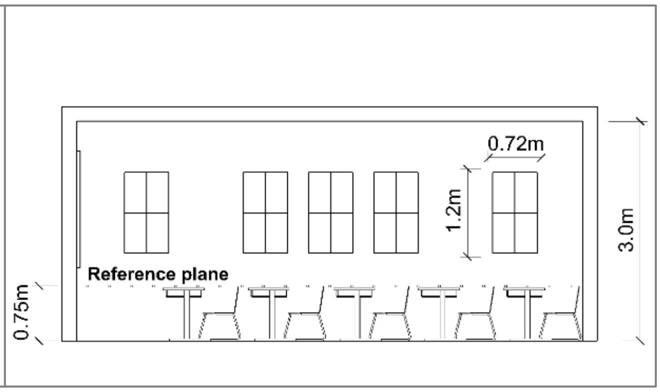


Figure 4: section of the simulated classroom

Table 2: Parameters of simulated classroom

Space parameters		Windows parameters	
Dimensions	4.50m X 6.9m X 3.0m	WWR	21%
Working level	+0.75m	No. of Windows	5
Surface Reflectance		Dimensions	0.72m x 1.2m
Interior walls	50%	Sill height	1.15m
Exterior walls	35%	Glass Transmission	88%
Ceiling	80%	**Solar Screens parameters**	
Floor	20%	Cell size	6cm x 6cm
Furniture	50%	Perforation Rates	N&W&S: 90%, E: 80%
White board	90%	Depth ratios	N&W: 0.15, E: 0.75, S: 0.6
Solar screens	70%	Screen reflectance	70%

Simulation process

To conduct the virtual simulation three software tools were used. The software “Rhinoceros”, which is a 3D modelling tool, was used to build geometries of the modelled classroom and perforated screens with different configurations. “DIVA” is a plug-in for ‘Rhinoceros’ (Jakubiec, Reinhart, 2011) and is used as an interface for the simulation engines “Radiance” and “Daysim”. Both software engines are broadly used for backward-tracing daylighting analysis and have been previously validated by comparing simulation results with physical measurements (Reinhart, Breton, 2009). “Grasshopper”, a generic algorithm editor that works as a parametric modelling extension for Rhinoceros (Rutten, McNeel, 2012), was used to produce the variation of solar screens according to the required parameters. “Grasshopper” was also used with “DIVA” to control the simulation runs and export the results.

The location is Riyadh (24.7°N, 46.8°E). The weather data file for Riyadh was obtained from the U.S Department of Energy (DOE, 2015). Weather files represent a Typical Meteorological Year “TMY” and are generated using recorded data including global solar radiation from around 23 years (Hall et al, 1978). The sky condition setup in this study was “clear sky with sun” as this is a typical sky condition in this climate (Al-Abbadi et al, 2002).

Simulation parameters used for Radiance simulation engine are presented in Table 3. The “ambient bounces” represents the number of times the light is allowed to hit and bounce from any plane in the simulated scene, and the recommended value is at least 6 to account for complicated configuration such as perforated screens (IES, 2012). The “ambient divisions” parameter determines the number of sample rays sent out from a surface point. It is recommended to be set at as high as 1000 to avoid high brightness variation (Reinhart, Wienold, 2011). An ambient sampling parameter greater than zero determines the number of extra rays that are sent in sample areas with a high brightness gradient. The combination of “ambient accuracy” ”, “ambient resolution” and the maximum scene dimension gives a measure of how fine the luminance distribution is distributed, according to this formula: [(Maximum scene dimension × ambient accuracy) / ambient resolution] (Larson, Shakespeare, 2004). Hence, setting the “ambient accuracy” at 0.1 and “ambient resolution” at 300 with a maximum scene dimension of 100m means that the smallest cell in simulated perforated screens can be as small as 3cm because (100m × 0.1)/300 = 0.03m.

Table 3: Utilized Radiance Simulation Parameters

Ambient bounces	Ambient divisions	Ambient sampling	Ambient	Ambient accuracy
6	1000	20	300	0.1

A grid of measuring sensors is used as a reference plane to plot the metrics’ data. The reference plane is recommended to be on the highest plane where regular task is performed in the space (IES, 2012). In the case of a classroom, the reference plane is set on pupils desks at 0.75m height Figure 4. There are in total 345 measuring points on the reference plane, spread evenly on a 0.3mx0.3m grid, this grid is the minimum recommended grid to improve accuracy (IES, 2012).

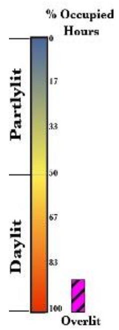
To simulate DAv, we need to set a required illuminance threshold and provide an occupancy schedule. The standard adequate illuminance for a reading and/or writing task is 500lx (Phillips, 2000), however, it is problematic to depend on daylight solely to achieve this level without causing discomfort glare (Mardaljevic et al, 2009). Therefore, the required illuminance threshold was set to 300lx since the aim was to reduce the use of artificial light as much as possible (Heschong et al, 2012). The occupancy schedule is created using a typical school year in Saudi Arabia, which has 180 days in 36 weeks, with a total of 1080 hours, the school year starts on mid-September until mid-June in two semesters, each term has one half term break. The school day starts at 6:30 and ends at 13:30 to avoid the hot afternoon hours as much as possible.

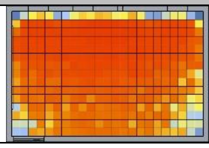
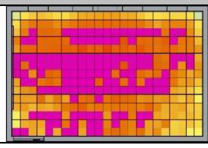
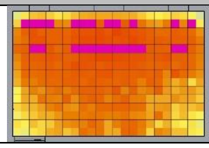
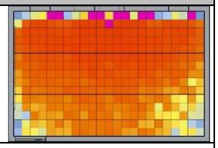
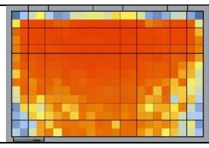
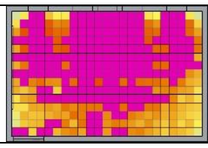
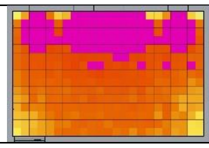
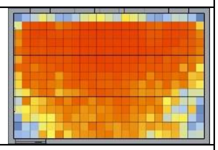
Results

Each of the 345 measuring points is represented by a coloured square on the classroom plan to show daylight availability distribution. The colour of each square indicates the percentage of time achieving 300lx out of total occupancy time according to a colour scale ranges from Blue 0% to Red 100%. Squares in magenta colour represent Overlit conditions. Table 4 compares DAv distribution for the best and worst case for each orientation. The percentage of Daylit area of the total classroom area is then calculated for each case in each orientation. The graph in Figure 5 displays Daylit areas for all cases. Cases achieved more than 50% daylit area is considered adequate to achieve acceptable daylight performance (Sherif et al, 2012).

Table 4: Comparison between daylight availability distribution of best and worst case for each orientation

Legend

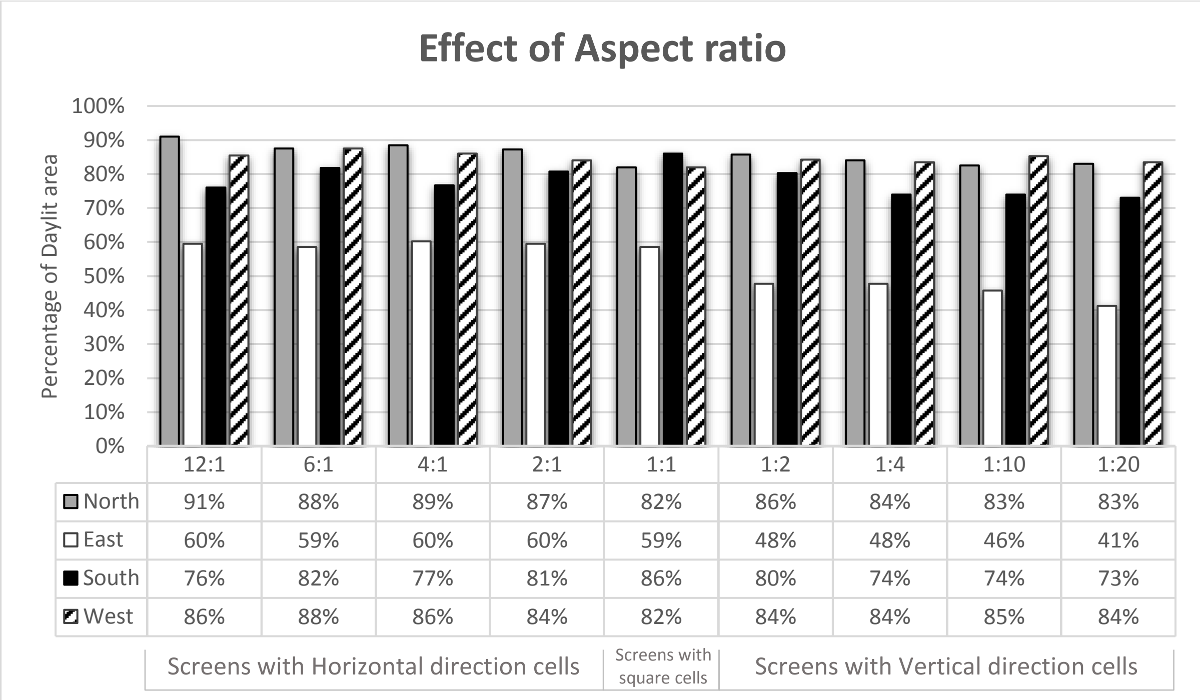


	North	East	South	West
Best Case				
H:V	12:1	4:1	1:1	6:1
Daylit area	91%	60%	86%	88%
Worst Case				
H:V	1:1	1:20	1:10	1:1
Daylit area	82%	41%	73%	82%

Results in Figure 5 show that using screens with horizontal direction cells could provide more daylit area in the studied context for all main orientations except South orientation, and screens with vertical direction provide also more daylit area than screens with square cells for the North and West orientations. In the South Orientation the optimum aspect ratio is 1:1 with square cells, using other aspect ratio for Southern orientation could reduce the daylight performance of the solar screen.

Discussion and Conclusion

To provide more daylit area, results of this study recommend using different aspect ratio than 1:1 in the North and West facades, and using 1:1 aspect ratio in the South. For the East orientation, results recommend using only screens with horizontal direction cells. Most cases of aspect ratios in all main orientations achieved adequate level of daylighting performance providing daylit area of more than 50% of total space. Only the screens with vertical direction in the East orientation failed to achieve adequate daylit areas as shown in Figure 5, in these cases, overlit areas occupied about half of the total area of the classroom Table 4. It must be noticed that the result of West façade reflects the occupation schedule used in this context as the school day finishes early. Which differs from studies of residential spaces where occupation schedule extend until sunset.



	12:1	6:1	4:1	2:1	1:1	1:2	1:4	1:10	1:20
North	91%	88%	89%	87%	82%	86%	84%	83%	83%
East	60%	59%	60%	60%	59%	48%	48%	46%	41%
South	76%	82%	77%	81%	86%	80%	74%	74%	73%
West	86%	88%	86%	84%	82%	84%	84%	85%	84%

Figure 5: percentage of Daylit area for all cases

Results of previous studies by the authors recommended using 90% perforation rate in North, West and South facades, 80% in the East facades. It also recommended depth ratio of 0.15 in North and West Facades, 0.6 in West facades, 0.75 in East Façade. Results of this experiment proved that using the recommended results by the authors in previous studies could achieve adequate daylight performance when using any aspect ratio, except for East façade where screens with vertical direction did not achieve adequate daylit levels. Hence, architects could use different aspect ratios according to the required daylit area provided using the chart in Figure 5.

References

Abanomi, W., Jones, P. (2005). Passive cooling and energy conservation design strategies of school buildings in hot, arid region: Riyadh, Saudi Arabia. In: *Passive and Low Energy Cooling for the Built Environment*. Santorini, Greece, 19-21 May 2005.

Al-Abbadi, N.M., Alawaji, S.H., Bin Mahfoodh, M.Y., Myers, D.R., Wilcox, S., Anderberg, M. (2002). Saudi Arabian solar radiation network operation data collection and quality assessment. *Renewable Energy,* 25(2), 219-234.

Alitany, A.K. (2014). *A new strategy of ICT integrated methodologies for 3D documentation : a case study of the projected wooden windows (The Roshans) in the historical city of Jeddah (Saudi Arabia).* PhD. Universitat Politècnica de Catalunya.

Aljofi, E. (2005). The Potentiality of Reflected sunlightthrough Rawshan screens. In: *Passive and Low Energy Cooling for the Built Environment*. Santorini, Greece, 19-21 May 2005.

BSI, B.E. (2007). *15251, Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.*

DOE, (2015). *Weather data file for Riyadh Saudi Arabia*. [Online]Available from:
http://apps1.eere.energy.gov/region=2_asia_wmo_region_/country=Saudi%20Arabia
[Accesed:14/10/2015]

Erwin, B., Heschong, L. (2002). Lighting for Learning. In: *Lightfair International Seminar*. Sanfrancisco, CA, 5 June 2002.

Fathy, H. (1986). *Natural energy and Vernacular architecture: principles and examples with reference to hot arid climate.* Chicago: University of Chicago.

Hall, I.J., Prairie, R., Anderson, H., Boes, E. (1978). *Generation of a typical meteorological year.*(SAND-78-1096C; CONF-780639-1).

Harris, C. (2006). *Solar screen,* fourth ed. New York: McGraw-Hill books.

Heschong, L., Group, H.M. (2012). *Daylight Metrics*. [Online] Available from: http://www.energy.ca.gov/2012publications/CEC-500-2012-053/CEC-500-2012-053.pdf [Access:14/2/2016].

IES, D.M.C. (2012). *Approved Methods: IES Spatial Daylight Autonomy sDA and Annual Sunlight Exposure.*

Jakubiec, J.A., Reinhart, C.F. (2011). DIVA 2.0: Integrating daylight and thermal simulations using Rhinoceros 3D, Daysim and EnergyPlus. In*: Conference of International Building Performance Simulation Association*, Sydney, Australia, 14-16 November 2011.

Kotbi, A., Ampatzi, E. (2015). Using Mashrabiya to enhance daylighting and privacy in girls' schools in Saudi Arabia. a poster in In: *the 6th Daylight Symposium,* London, UK, 2-3 September.

Kotbi, A.G., Ampatzi, E. (2016). Using solar screens in school classrooms in hot arid areas: the effect of different perforation rates on daylighting levels. In: *32th PLEA conference on Passive and Low Energy Architecture,* Los Angeles, CA, 11-13 July 2016.

Larson, G.W., Shakespeare, R. (1998). *Rendering with Radiance: the art and science of lighting visualization*. Sanfrancisco: Morgan Kaufmann Publishers.

Mardaljevic, J., Heschong, L., Lee, E. (2009). Daylight metrics and energy savings. *Lighting Research and Technology,* 41(3), 261-283.

Nabil, A., Mardaljevic, J. (2006). Useful daylight illuminances: A replacement for daylight factors. *Energy and Buildings,* 38(7), 905-913.

Phillips, D. (2000). *Lighting modern buildings,* Oxford: Architectural Press.

Reinhart, C., Breton, P.F. (2009). Experimental Validation of Autodesk 3ds Max 2009 and Daysim *LEUKOS,* 6(1), 7-35.

Reinhart, C.F., Mardaljevic, J., Rogers, Z. (2006). Dynamic Daylight Performance Metrics for Sustainable Building Design. *LEUKOS,* 3(1), 24.

Reinhart, C.F., Walkenhorst, O. (2001). Validation of dynamic RADIANCE-based daylight simulations for a test office with external blinds. *Energy and Buildings,* 33(7), 683-697.

Reinhart, C.F., Wienold, J. (2011). The daylighting dashboard –A simulation-based design analysis for daylit spaces. *Building and Environment,* 46(2), 386-396.

Rutten, D., McNeel, R. (2012). *Grasshopper*. www.Grasshopper3d.com. [14/12/2015].

Sabry, H., Sherif, A., Gadelhak, M., Aly, M. (2014). Balancing the daylighting and energy performance of solar screens in residential desert buildings: Examination of screen axial rotation and opening aspect ratio. *Solar Energy,* 103, 364-377.

Sabry, H., Sherif, A.H., Rakha, T. (2011). Daylighting Efficiency of External Perforated Solar Screens: Effect of Screen Axial Rotation under Clear Skies. In: *International Conference on Sustainable Design and Construction (ICSDC) 2011*, Kansas city MO, 23-25March.

Sherif, A., El-Zafarany, A., Arafa, R. (2012). External perforated window Solar Screens: The effect of screen depth and perforation ratio on energy performance in extreme desert environments. *Energy and Buildings,* 52(0), 1-10.

Sherif, A., El Zafarany, A., Arafa, R. (2013). Evaluating the energy performance of external perforated solar screens: Effect of screen rotation and aspect ratio. In: *SB13 Sustainable Building 2013*, Singapore, 9-10 September.

Sherif, A., Sabry, H., Rakha, T. (2012). External perforated Solar Screens for daylighting in residential desert buildings: Identification of minimum perforation percentages. *Solar Energy,* 86(6), 1929-1940.

Sherif, A., Sabry, H., Gadelhak, M. (2012). The impact of changing solar screen rotation angle and its opening aspect ratios on Daylight Availability in residential desert buildings. *Solar Energy,* 86(11), 3353-3363.

Webb, A.R. (2006). Considerations for lighting in the built environment: Non-visual effects of light. *Energy and Buildings,* 38(7), 721-727.