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Assessment of Building Façade Performance in-Terms of Daylighting and Associated Energy Consumption in Architectural Spaces

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ABSTRACT: This paper examines the effect of vertical and horizontal shading devices on the quality of daylight in buildings and the associated energy saving. Excessive daylight in architectural spaces contributes negatively to the energy consumption in buildings. Blinds and shading devices are good solutions to attenuate the surplus amount of daylight in spaces. Accordingly, this study evaluates the effect of shading devices on the amount of light flux and the associated solar energy in buildings. It estimates the energy consumption attributed to lighting spaces for three common positions of shading devices. Computer simulation strategy was undertaken to correlate the illuminance level in spaces with room geometry and architectural shading elements. The Holophane model for lighting calculations was used to estimate the average illuminance level on workplane and correlate it with the expected saving energy in buildings. The study concluded that there is an optimal orientation for shading devices that keeps the internal illuminance level within the acceptable range with minimum amount of solar heat gain.

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Very innovative approaches have been adopted to enhance the performance of building facades and to obtain productive environments for building occupants. Several researchers worked on optimizing daylighting deliberately (Li-Danny and Lam-Joseph, 2003). They followed new technologies different from the classic methods for shading. These technologies are effective ways for controlling illuminance level in office buildings (Inoue, 2003). Researchers are also interested in blinds as effective shading devices; this field has several studies that depict the great concern in blocking the sun to create good daylighting systems.

They primarily focus on the effect of shading devices on light distribution and the quality of daylighting in spaces (Freewan et *al*., 2009; Alzoubi, 2005). In computer-related field, several studies utilized computation for problem solving in such kind of research. Coupling lighting and energy were among those problems solved by computer simulation. This combination explores the importance of coupling in decreasing the energy consumption while keeping good lighting quality (Malkawi, 2004). The optical and thermal performance of glazing has also been integrated with shading devices to keep good level of illuminance in spaces in many recent studies (Breitenbach *et al*., 2001). These studies consider the self-responsive of façade parameters as one way of blocking the unnecessary amount of light and heat gain from the sun. For instance, the thermo-tropic glass proved to be a good solution to self-dim the excessive daylighting in spaces and to attenuate the heat gain in summer (Inoue, 2003). Therefore, evaluating lighting performance in spaces should be associated with the energy consumption and thermal situation in spaces. Good daylighting design integrated with solar heat gain can result in substantial energy saving in spaces (Li-Danny and Lam-Joseph, 2003). Accordingly, this study aims at assessing the performance of different positions of shading devices to find the optimal situation in terms of good daylighting with minimum amount of heat gain in spaces.

MATERIALS AND METHOD

The study was conducted under the umbrella of post positivism system of inquiry. The method focused on measuring lighting in a typical small office. The simulation setting used an office ideally dimensioned with standard window size (3 m^2) for lighting measurements (Figure 1).

The dimensions of the space were 5.5 m (width) × 5.5 m (length) × 2.7 m (height) (Figure2). The reflectance of the ceiling, walls and floor was assumed to be 0.9, 0.7 and 0.4, respectively, which are regular values for an office space. The window was 2 m (W) × 1.5 (H) with a ratio to wall area on internal envelope of 22%. The transmittance of the window in the simulation was 0.90 (Figure 3).

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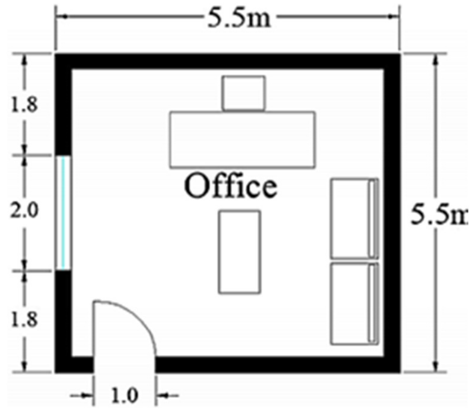


Fig 1: A plan for the office used to conduct computer simulations for lighting analyses (Drawn by the author).

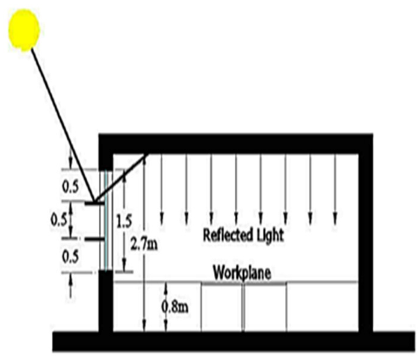


Fig 2: A section in the office used for lighting simulation (Drawn by the author).

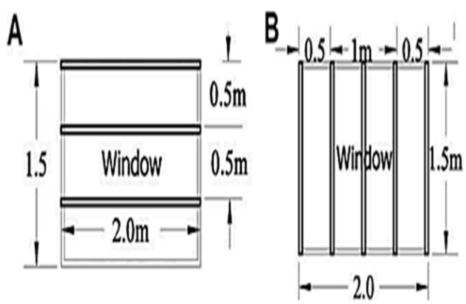


Fig 3: (A) Horizontal shading devices placed on the studied office; (B) vertical shading devices placed on the studied office.

The shading devices were simple louvers of 2 m (L) × 0.4 m (W) 0.05 m (D) and the distance between the louvers (W) × 0.5 m. The color of the shading devices was assumed to be white with reflectance factor of 0.75. The walls of the office were made of plywood with brownish color (RGB = 0.75, 0.5, 0.00). The floor was assumed made of marble and the ceiling covered with polystyrene panels.

The furniture was assumed to have low-reflectivity colors, which is very close to reality (Table 1). The latitude of the office place was 32° and the longitude was 36° and the sky was assumed having clear conditions (Table 2).

Table 1: The parameters of a typical office used for computer simulation.

Office parameter	Material	Color: red, green, blue (RGB)	Average reflectance value
Walls	Plywood	0.75, 0.5, 0.00	0.7
Floor	Marble	0.75, 0.75, 0.50	0.4
Ceiling	Polystyrene	1.0, 1.0, 0.9	0.90
Furniture	Fabric, wood	Various	~0.3

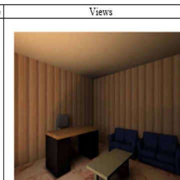
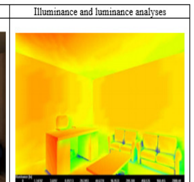
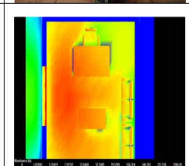
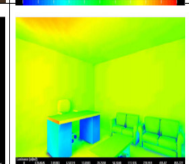
Table 2: Related information to the computer simulation.

Date of simulation	June 21st
Latitude	32°
Longitude	36°
Sky conditions	Clear

RESULTS AND DISCUSSION

The results of the simulations focused on the illuminance distribution for horizontal work plane and the opposite wall as a vertical work plane for some visual tasks (Table 3). The illuminance values across the line linking the midpoint at the window to the opposite wall were correlated with the distance from window (Figure 4). As shown in Table 4, every case of shading positions has its mathematical formula for estimating the illuminance value. The lowest illuminance values occurred in the case of horizontal shading devices tilted 45 with the horizon (Table 4). As shown in Table 5, the lowest average illuminance level on horizontal work plane occurred in the case of horizontal shading devices at 45.

Table 3: Analyses of illuminance and luminance distribution on the surfaces of the studied office

Time and date	Views	Illuminance and luminance analyses
June 21st, 12 pm		
June 21st, 12 pm	 distribution	

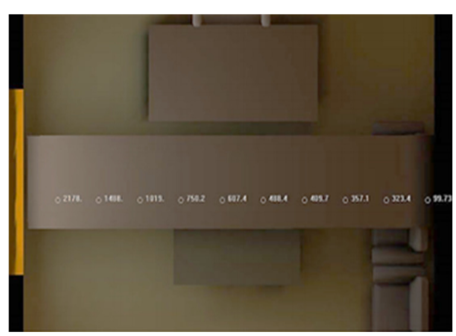


Fig 4: Normal analysis of illuminance level on work plane using lights cape software.

The horizontal shading devices with zero tilting angles kept the average illuminance level around 473 lux and 259 lux on horizontal and vertical work planes respectively (Figure 5). The standards Illumination Engineering Society of North America (IESNA). According to Holophane model, the average illuminance level at a given surface is given as follows: E (LUX) = Light flux (lumen) / Room area (Am^2)
The amount of light flux (lumen) is computed by rewriting the above equation as follows: Light flux (lumen)= EA
where E is the standard illuminance level in the office (lux) and A is area of the office (m^2).
Based on the simulation results, the illuminance level due to sunlight at the workplane was represented in the office as a function of distance from window for different shading devices as follows:

Without shading devices: $E= 1524X^{-1.035}$ 1
Vertical shading devices: $E= 1086X^{-1.015}$ 2
Horizontal shading devices: $E= 877X^{-0.83}$ 3
Horizontal shading devices (45°): $E = 662X^{0.85}$ 4

Table 4: The integrative equations of lumen values on workplane strip as a function of distance from window, X.

Shading position	Total incident lumen equation	Limits of surplus light energy (m)	Limits of needed light energy (m)
Without shading devices	$[43542X^{-0.035}]$	0.10- 2.90	2.90-5.0
Vertical shading devices	$[71447X^{-0.015}]$	0.10-2.15	2.15-5.0
Horizontal shading devices	$[5289X^{0.17}]$	0.10-2.0	2.0-5.0
Horizontal shading devices, 45°	$[4335X^{0.15}]$	0.10-1.40	1.4-5.0

To find the total lumen (U) mathematical integration was applied on the illuminance equations as follows:

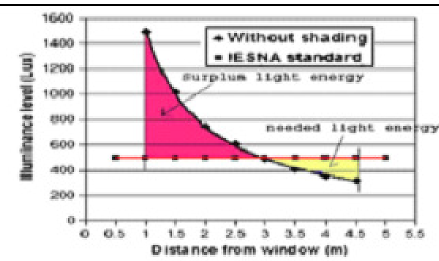
(No shading devices): $\phi = w \int_{0.1}^{5} 1524X^{-1.035}dx$ 5
(Vertical shading devices): $\phi = w \int_{0.1}^{5} 1086X^{-1.015}dx$ 6
(Horizontal shading devices): $\phi = w \int_{0.1}^{5} 877X^{-0.83}dx$ 7
(Horizontal shading devices; 45°): $\phi = w \int_{0.1}^{5} 662X^{-0.85}dx$ 8

The integration was performed for all positions of shading devices as shown in Table 5. Table 5 illustrates the surplus illumination in red color and the needed light in yellow color.

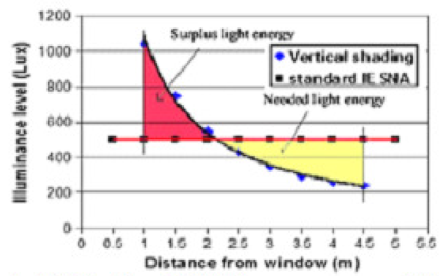
This study concluded that there is an optimal position for the sun breakers that can work positively in terms of architectural space quality. Vertical shading devices can simultaneously provide good daylighting and minimum heat gain in spaces. It is recommended that architectural designers be full aware of this fact. For south exposure facades, vertical louvers can be used as they are good in energy saving. It is essential that this factor be tested to make sure that the shading devices do not block the outdoor views.

Table 5: The power needed to fulfill the IESNA standards for different shading devices.

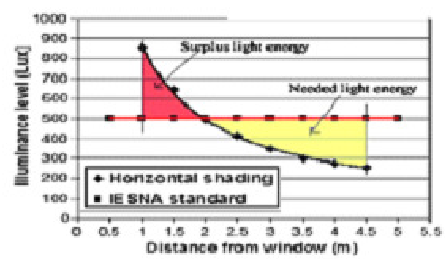
Light flux on workplane for different shading devices for both above and below the IESNA standards



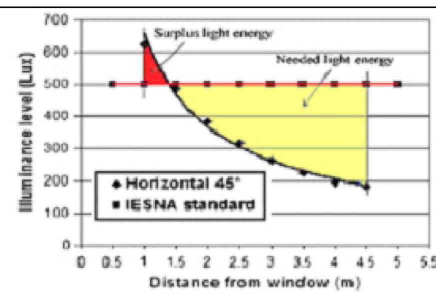
Surplus light flux above IESNA limit = 3847.1
Needed light flux to fulfill IESNA limit = 257.8
Power needed to idealize lighting situation, W/unit area = 25.6



Surplus light flux above IESNA limit = 2301.5
Needed light flux to fulfill IESNA limit = 536.5
Power needed to idealize lighting situation, W/unit area = 10.2



Surplus light flux above IESNA limit = 1424.6
Needed light flux to fulfill IESNA limit = 497.0
Power needed to idealize lighting situation, W/unit area = 17.3



Surplus light flux above IESNA limit = 840.5
Needed light flux to fulfill IESNA limit = 840.7
Power needed to idealize lighting situation, W/unit area = 46.7

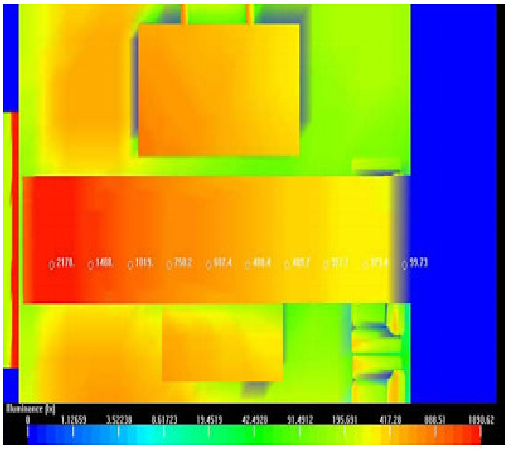


Fig 5: Logarithmic analysis of illuminance level on work plane using lights cape software.

By integrating the energy consumption, the illuminance levels, and the visual requirements, the quality of architectural spaces will be enhanced as well.

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