

Effect of Orientation of the Wall Window on Energy Saving under Clear Sky Conditions

Madhu Sudan, G. N. Tiwari

Abstract—In this paper, an attempt has been made to analyze the effect of wall window orientation on Daylight Illuminance Ratio (DIR) and energy saving in a building known as “SODHA BERS COMPLEX (SBC)” at Varanasi, UP, India. The building has been designed incorporating all passive concepts for thermal comfort as well as daylighting concepts to maximize the use of natural daylighting for the occupants in the day to day activities. The annual average DIR and the energy saving has been estimated by using the DIR model for wall window with different orientations under clear sky condition. It has been found that for south oriented window the energy saving per square meter is more compared to the other orientations due to the higher level of solar insolation for the south window in northern hemisphere whereas energy saving potential is minimum for north oriented wall window. The energy saving potential was 26%, 81% and 51% higher for east, south and west oriented window in comparison to north oriented window. The average annual DIR has same trends of variation as the annual energy saving and it is maximum for south oriented window and minimum for north oriented window.

Keywords—Clear sky, Daylight Illuminance Ratio, Energy saving, Wall window.

I. INTRODUCTION

WINDOWS are key elements in architecture, as they allowing daylight inside the building and represent the most basic resource [1]. Window area affects the amount of daylighting as well as influences heat gain and loss. Daylighting and thermal comfort are often in conflict with one another: that is, the increases the window area the increases the daylight inside the building, but also the greater the heat loss. The proper design of windows also brings a notable energy saving in artificial lighting and improves thermal comfort [2], [3]. The evaluation of daylight inside the room through window DIR is the most common and simplest measurement [4]-[6]. The DIR are evaluated under clear sky condition, the sun's position is relevant, and so the calculation is dependent on the location of the room. Therefore, the measurement of DIR depends on time, window orientation, inclination as well as location of the room.

The major energy consumption in the fully air-conditioned office building is account for 20-30% of the total electricity, whereas it is 10% for the residential buildings. Daylight provides an exciting new technique for reducing energy consumption along with delivering significant benefits

Madhu Sudan is with the Centre for Energy Studies, Indian Institute of Technology Delhi, Hauz Khas, New Delh-110016, India (corresponding author phone: +91-11-26596469; e-mail: msudan.esz@gmail.com).

G. N. Tiwari is with Centre for Energy Studies, Indian Institute of Technology Delhi, Hauz Khas, New Delh-110016, India.

associated with natural lighting in commercial and residential complex. Daylighting concept in the building is an effective option of saving fossil fuels i.e. conventional fuel, which ultimately leads to saving the substantial amount of money and reducing the emission of greenhouse gases [7], [8]. Daylight factor was used in the earlier studies as a performance metric to evaluate daylight quantity. It is known as static daylight metric which is the interior and exterior illuminance ratio that quantifies the amount of diffuse skylight under overcast sky condition [7].

As the luminance distribution of an overcast sky is symmetrical about the vertical axis going through the zenith and the direct sunlight is excluded from the scenario, this method has two disadvantages: first one, insensitive to the building orientation with respect to the sun and secondly, insensitive to the intended locale of the building and climate [7], [8]. In this communication, the effect of the orientation and obstruction on DIR has been analyzed. Further, energy saving for differently oriented wall window has been determined.

II. METHODOLOGY

The photograph of the building known as SODHA BERS COMPLEX (SBC) has been shown in Fig. 1. The daylight and energy performance of the wall window has been determined theoretically. To calculate the DIR and energy saving following methodology has been adopted.

- Step 1: Illuminance level and DIR for east, south, west and north oriented wall window has calculated by using (1) and (2), respectively. The value of the perimeters used in (1) and (2) are tabulated in Table I.
- Step 2: Monthly DIR has been determined by adding daily DIR.
- Step 3: For assessment of the annual energy saving, same expression has been used as in [7].



Fig. 1 SODHA BERS COMPLEX (SBC) with room

TABLE I
PARAMETRIC VALUES USED TO DETERMINE THE DAYLIGHT FACTOR

Sr.No	Parameters	Value
1	Total area of the room surfaces (A_t , m ²)	86
2	Floor area of the room (A_f , m ²)	15
3	Transmittance of glazing (τ)	0.8
4	Maintenance correction factor ($0.5 \leq M \leq 0.9$)	0.6
5	Total glazing area of window (A_g , m ²) for the room	0.68
6	Vertical height between working surface and center of the window (H_{cw} , m)	1.2
7	For vertical window (β , degrees)	90
8	Total height of the room (H_R , m)	3.5
9	Total length of the room (L , m)	5
10	Vertical angle of visible sky from the center of the window (θ , degrees)	90
11	Total width of the room (W , m)	3
12	Average reflectance of all room-surfaces ($0 \leq R \leq 1$)	0.6
13	Artificial light luminous efficacy (ϵ_e , lm/W) (CFL lamp)	70
14	Ballast factor (B_f)	0.90

A. Daylight Illuminance Ratio, DIR (%)

Daylight Illuminance Ratio (DIR) can be expressed as:

$$DIR = \left(\frac{E_i}{E_o} \right) \times 100 \quad (1)$$

where, E_i is the daylight illuminance inside room and E_o is the outside illuminance. Further [8] had developed and validated Daylight Illuminance Ratio (DIR) model that predict the DIR and daylight metrics at a given point considering effect of orientation and position of the wall window as [7]:

$$DIR = \left(\frac{E_i}{E_o} \right) \times 100 = \left[\frac{\tau \times A_g \times M \times \theta}{A \times (1 - R^2)} \right] \times \left[1 + \frac{L}{2} \left(\frac{1}{\sqrt{l^2 + h_{cw}^2 + w^2}} \right) \right] \times (1 + \cos \theta_i) \quad (2)$$

where L , l , w and $\cos \theta_i$ are the total length of a room, perpendicular length of the observational point from the aperture (m), the perpendicular height between the observation point the perpendicular aperture axis (m), the perpendicular length of the observation point from perpendicular axis along the width axis of the aperture (m) and the angle of incidence, respectively.

III. RESULTS AND DISCUSSION

To compute the mathematical equations, software MATLAB10a has been used. The theoretical results for the Daylight Illuminance Ratio (DIR) energy saving have been briefly discussed in this section.

Fig. 2 represents the hourly variation of the solar radiation and outside illuminance for a clear day on March, 2014. Fig. 3 shows the effect of differently oriented wall window on DIR for a typical clear day on March 2014. The solar intensity and corresponding outside illuminance at the horizontal surface first increases till 12:00 and then decreases with time. Daily average DIR has been found 1.05, 1.61, 1.28 and 0.72 for east, south, west and north oriented wall window.

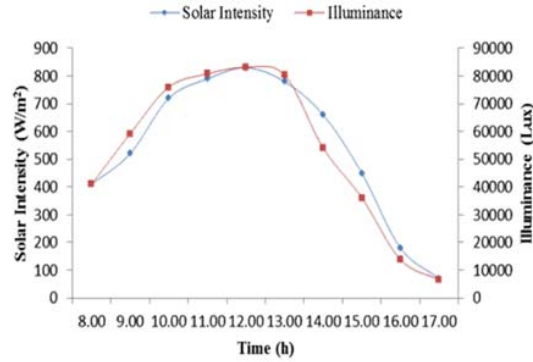


Fig. 2 Hourly variation of solar radiation and outside illuminance at horizontal surface on March 2015

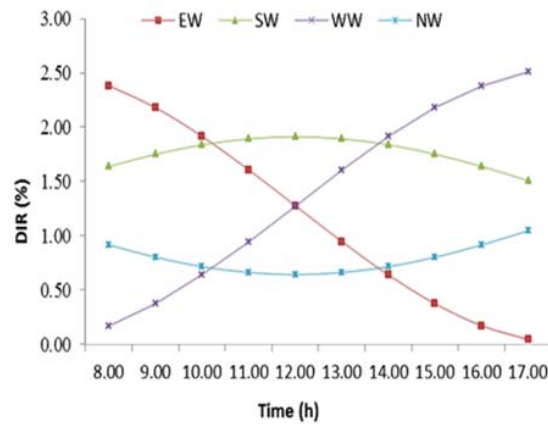
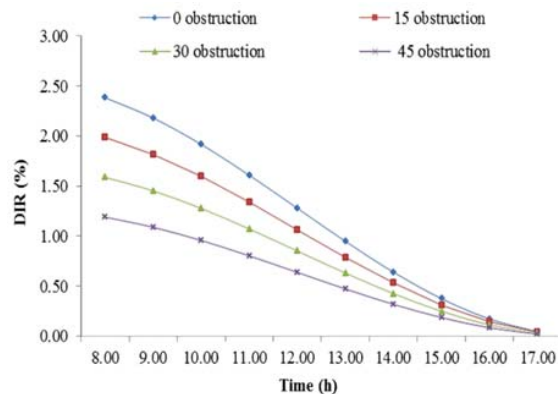
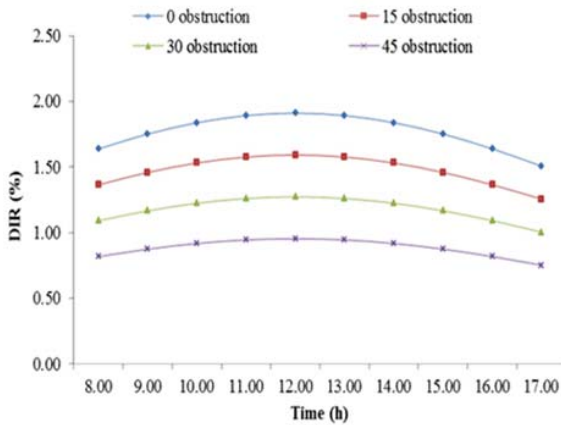


Fig. 3 Hourly variation of DIR for different orientation

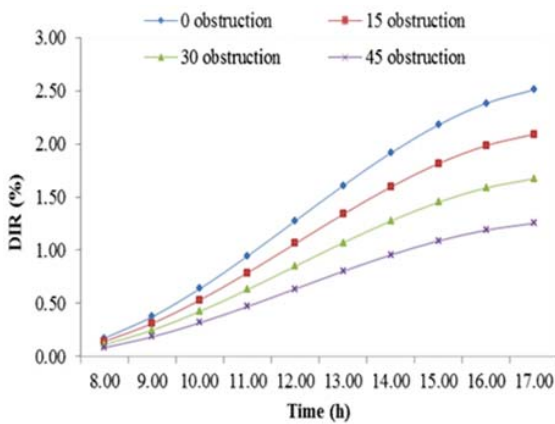
The analysis of the result investigated that for the south oriented window is preferable compared to the other oriented windows due to the higher level of solar insolation for the south window in northern hemisphere. Figs. 4 (a)-(d) show the variation of the DIR when change the obstruction of the wall window. They illustrate increases the obstruction decrease the DIR for all orientation.



(a) Effect of obstruction on DIR for north window



(b) Effect of obstruction on DIR for south window



(c) Effect of obstruction on DIR for west window

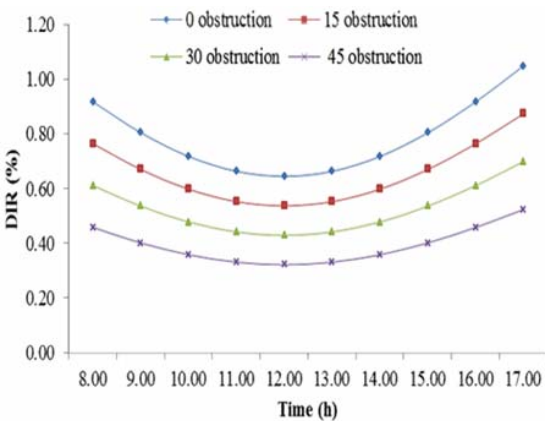


Fig. 4 (d) Effect of obstruction on DIR for north window

Monthly average variation of DIR is tabulated in Table II. Annual average value of the DIR was found to be 1.51%, 2.18%, 1.82% and 1.15% for east, south, west, and north oriented wall window, respectively.

Monthly variation of the energy saving for differently oriented wall window has been shown in Fig. 5. It indicates that the energy saving increases from January to May and

decreases from July to December. It is inferred that the maximum energy saving potential is in May while it is minimum in December for all orientations. The energy saving potential was 26%, 81% and 51% greater for east, south and west oriented window in comparison to north oriented wall window in the Varanasi India climate conditions. It is clear from the Fig. 5 south oriented window received the maximum energy saving potential in winter while, it is minimum in summer. It is due to that a south facing window receives higher amount of DIR during winter than during the summer because the altitude is greater in summer compared to that in winter for a given inclination (β).

TABLE II
MONTHLY AVERAGE VALUE OF DIR FOR DIFFERENT ORIENTATION

Month	East	South	West	North
Jan	1.52	2.70	1.82	0.63
Feb	1.51	2.53	1.82	0.80
Mar	1.50	2.25	1.83	1.07
Apr	1.51	1.94	1.83	1.40
May	1.51	1.68	1.82	1.66
Jun	1.52	1.58	1.82	1.75
Jul	1.52	1.60	1.81	1.74
Aug	1.51	1.82	1.82	1.52
Sep	1.50	2.17	1.82	1.16
Oct	1.50	2.47	1.82	0.87
Nov	1.51	2.68	1.81	0.66
Dec	1.52	2.75	1.81	0.59
Annual average	1.51	2.18	1.82	1.15

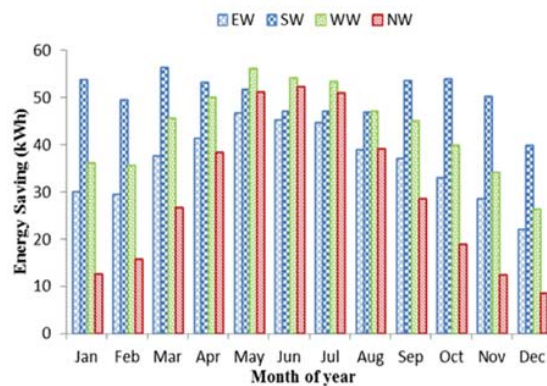


Fig. 5 Annual energy saving by the daylight for different oriented wall window

IV. CONCLUSIONS

- a) South window is a preferable window for the daylight in the northern hemisphere.
- b) The obstruction increases then daylight performance decrease the daylight performance of the window.
- c) The energy saving potential was 26%, 81% and 51% greater for east, south and west oriented window in comparison to north oriented wall window.

NOMENCLATURE

A_f floor area (m^2) of a room

A_g glazing area of the window (m^2) for a room
 A_t total area of room-surfaces (m^2)
 DIR percentage daylight factor (%)
 E_i internal illuminance (both direct and diffuse) a room on horizontal working surface (Lux or lm/m^2)
 E_o outside illuminance (both direct and diffuse) on horizontal surface (Lux or lm/m^2)
 H total height of a dome (m)
 H_R total height of a room (m)
 h vertical height of the given point above the ground surface (m)
 H_{1cw} vertical height between working surface and center of the window (m)
 H_{2cw} vertical height between ceiling of room and center of the window (m)
 L total length of a room (m)
 l perpendicular length of the given point from the wall window (m)
 M maintenance correction factor
 R average reflectance of all room-surfaces
 SBC SODHA BERS COMPLEX
 w perpendicular length of the given point from perpendicular axis along the width axis of the wall window (m)

Greek Letters

β inclination of the window (degrees)
 θ_w angle between the given point and the perpendicular axis to the window (degrees)
 θ_i angle of incidence (degrees)
 θ vertical angle of visible sky from the center of the window (degrees)
 τ transmittance of glazing

REFERENCES

- [1] S. Treado, G. Gillette, Kusuda T. Daylighting with windows, skylights, and clerestories. *Energy Build*; 6(1984) 319-30.
- [2] D.H.W. Li, A review of daylight illuminance determinations and energy implications, *Appl Energy* 87 (2010) 2109-18.
- [3] T.T. Chow, C. Li, Z. Lin, Innovative solar window for cooling-demand climate, *Solar Energy Materials & Solar Cells* 94 (2010) 212–220.
- [4] CIE, International lighting vocabulary. Commission Internationale de l'Eclairage 2011, CIE S 017:2011.
- [5] I. Acosta, C. Munoz, M. A. Campano, J. Navarro, Analysis of daylight factors and energy saving allowed by windows under overcast sky conditions. *Renewable Energy* 77 (2015) 194-207.
- [6] I. Acosta, J. Navarro, J. J. Sendra, Lighting design in courtyards: Predictive method of daylight factors under overcast sky conditions, *Renewable Energy* 71 (2014) 243-254.
- [7] Sudan, M., Tiwari, G.N., Al-Helal, I.M., 2015a. Dynamic analysis of daylight metrics and energy saving for rooftop window integrated flat roof structure of building. *Solar Energy* 122 (0), 834–846.
- [8] Sudan, M., Tiwari, G.N., Al-Helal, I.M., 2015b. A daylight factor model under clear sky conditions for building: An experimental validation. *Solar Energy* 115 (0), 379–389.