

APPLICABILITY OF A PRISMATIC PANEL TO OPTIMIZE WINDOW SIZE AND DEPTH OF A SOUTH-FACING ROOM FOR A BETTER DAYLIGHT PERFORMANCE

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ABSTRACT

This study examines the performance of attached prismatic panels, which have shading capability, in a side-lit deep plan room to find out the least possible WWR value in relation to room depth satisfying the required daylight availability. The methodology is based on simulating a base model in Relux and testing it with alternative models composed of incrementally defined WWR and room depth values. In accordance with minimum IES requirements, the most satisfying sDA value was found to be 48.54 % in a room of 12 m depth with 67 % WWR. An sDA of 51.59 % and 59.26 % was achieved in a room of 9m depth with 43 % WWR and 6m depth with 30 % WWR, respectively. The least ASE values were obtained with the least WWR alternative of 30 % in all room depths. This study presents a new approach with the consideration of innovative daylight redirecting systems to propose revisions for the requirements mentioned in standards about daylight in buildings but based on conventional fenestration systems.

Keywords: daylight, prismatic panels, windows, room depth

Abbreviations:

WWR:	Window-to-wall ratio
AR:	Aspect Ratio
sDA:	Spatial Daylight Autonomy
ASE:	Annual Sunlight Exposure
IES:	Illuminating Engineering Society
IEA:	International Energy Agency

1. INTRODUCTION

The effective daylight zone is limited to the window edge in a conventional side lighted space with a vertical window; areas further away from the perimeter zone receive considerably lower daylight [1]. Increasing window size to expand the effective daylight zone can contribute small gains in daylight levels at the rear part of the room but causes excessive solar radiation near the window [2]. This disproportional distribution of daylight in space results in thermal and visual discomfort in front part of the room while additional support from artificial lighting is required at the back, which means undesirable lighting conditions for the occupants [3]. Therefore, determining appropriate room and window ratio according to climatic conditions is significant terms of visual comfort and energy savings [4]. Especially in hot climatic regions, uniform distribution is required to achieve the desired visual and thermal comfort.

Using conventional solar shading devices, such as roller shades or venetian blinds, reduces the amount of daylight entering into room and worsens the daylight distribution across the space [5,6]. Innovative daylight systems have been proposed to overcome shortcomings of conventional daylight techniques. Prismatic daylight-redirecting panels, for instance, improve daylight distribution through sun shadings and redirections [7,8].

The purpose of the study is primarily to test the performance of attached prismatic panels in defining optimum window size and room geometry when

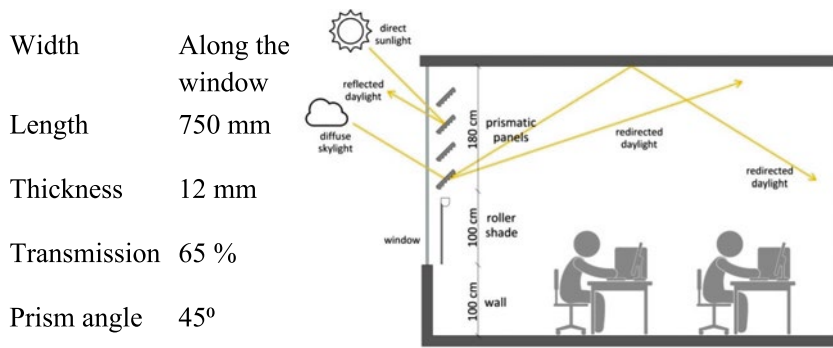


Fig. 1. Schematic illustration of prismatic panel principle and application

prismatic panels are installed in the side windows. The second aim is to provide sufficient daylight as deeply as possible into the space in every WWR-Room depth design alternatives and preventing excessive direct sunlight, which may cause negative impacts on occupants. The climate of Izmir is another significance meaning that, it would be possible to understand the applicability of a prismatic system in such a geographic and climatic location.

2. MODELLING THE BASE CASE ROOM

2.1. Daylight Illuminance and Optical Material Measurements

The base case is a deep-plan room having dimensions of 6 m by 12 m with 3.8 m height. Its window dimension is 5.5 m x 2.8 m. The daylight illuminance measurements were taken on December 21, 2017, at three times a day (9.30, 12.30, and 15.30) under overcast sky condition. A total of 19 measurement points was located with a spacing 0.6 m in the middle line of the room perpendicular to window line. Optical material properties were determined using both a luminance and illuminance meter as in reference [4]. Reflectance values of walls, ceiling and floor are 0.90, 0.85 and 0.60 respectively. The glazing has a transmittance value of 0.80.

Verification process included the comparison to determine how well Relux simulation outputs

match up with the actual measurement results. The coefficient of determination (R^2) was calculated to measure the accuracy of the simulation model. They were 0.93, 0.99, 0.97 in simulations ran for times 9.30, 12.30 and 15.30 respectively, indicating the high accuracy and verification of Relux software.

2.2. Prismatic Panel in Relux Model

Prismatic panels (Siteco 45/45) manufactured by company Siteco [9] were chosen to enhance the daylight quality in interior space. They are in louver form, placed inside the window at slat angle of 45°. Prismatic panels were installed at upper part of the window, between 2.00 m and 3.80 m above the floor. This position above the eye level prevents potential glare arising from daylight redirection through prismatic panels. The lower part of the window allows view outside. The distance between each panel was set to be 0.30 m. The identical prismatic panels were applied to all room depth-WWR configurations, Fig. 1.

2.4. Design Alternatives

Alternative room depths and window sizes were determined following standards in literature and modelled in Relux. First, limiting room depth for the reference room was determined using the equa-

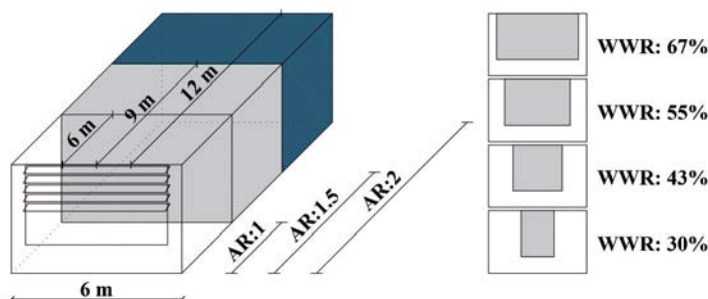


Fig. 2. Schematic view of stages in determining aspect ratios and window-to-wall ratios

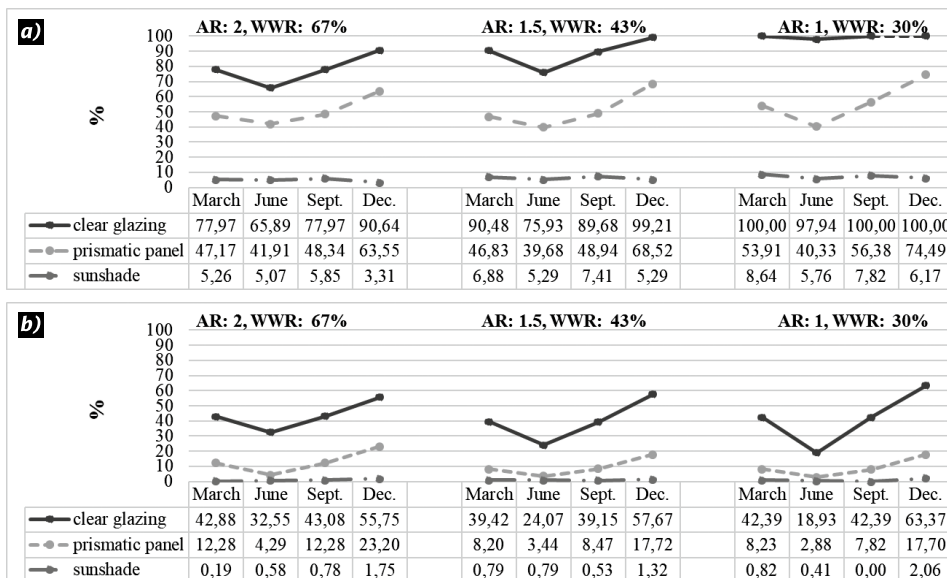


Fig. 3. Daylight performance of the rooms with optimum WWR and with respect to room depths: a) illuminance over 300 lx, b) illuminance over 1000 lx

tion described in The British Code BR8206(Part 2) [10] as:

$$\frac{L}{W} + \frac{L}{H_w} < \frac{2}{1 - R_b}, \tag{1}$$

where L is the room depth, W is the room width, H_w the window head height above floor level and R_b is the average reflectance of surfaces in the rear half of the room.

According to this equation (1), minimum acceptable room depth of the reference room was found as 9 m, indicating that room depth should not exceed this value to avoid gloomy looking and additional electric lighting in the rear half of the room. Taking limiting value into account, three floor aspect ratios of room depth to width were determined as follows:

AR= 1 (when room depth is 6 m, less than limiting value)

AR= 1.5 (when room depth is 9 m, equal to limiting value)

AR = 2 (when room depth is 12 m, greater than limiting value)

Since large windows increases exposure to sun and causes excessive heat gain and visual discomfort, the window area of each determined aspect ratio was incrementally reduced as shown in Fig. 2. Starting from the reference case with WWR of 67 %, the window width was reduced by 50 cm from both sides at each stage until minimum acceptable WWR of 30 % (due to British Code BR8206) [11] was achieved.

The reflectance of walls, ceiling and floor were assigned as 0.50, 0.85, 0.20, according to IEA Task

27 [11]. The measurement points were set to be 75 cm above the floor, 60 cm away from the walls surfaces and 60 cm spacing between each point. Totally 171, 126 and 81 measurement points were determined for the 12 m, 9 m and 6 m deep room, respectively. Simulations were run on solstice and equinox days at 10:00, 13:00 and 16:00. The 10 % transparent sunshade was considered at the lower part of the window to avoid excessive sunlight exposure since all measurements were carried out under CIE clear sky conditions in a room facing to South. In case of overcast sky conditions, additional sunshade would not be necessary, therefore the visual connection with the external environment would be possible.

3. FINDINGS

It is expected that the measurement points with illuminance above 300 lx will be as much as possible, and the measurement points with illuminance above 1000 lx will be as few as possible. Minimum acceptable floor areas are of 55 % for SDA and 7 % for ASE according to IES recommendations.

To simplify the calculation it was found that the illuminance at each measurement point represents the percentage of the annual working hours. For instance, it was assumed that each measurement point simulated in Relux for 21st March at 10:00 represents 180 working hours from 8 am to 11 am in the spring months. It corresponds to 7.5 % of total working hours in a year (considering 2400 working hours per year). Likewise, calculations at 13:00 and 16:00 represents 240 working hours from 11

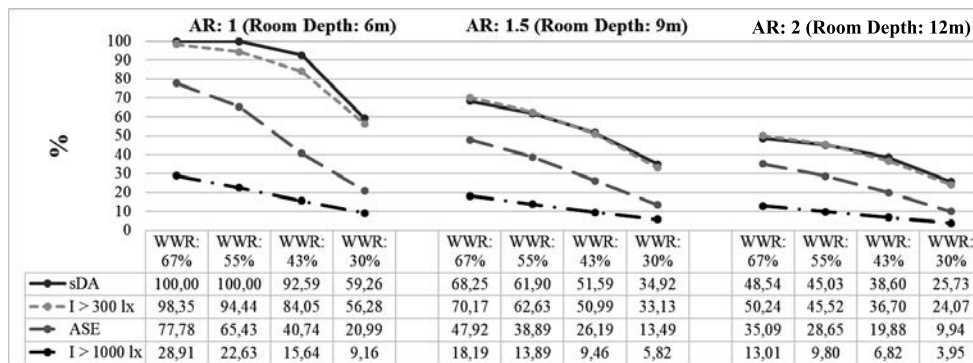


Fig. 4. sDA and ASE values with the percentage of analysis area that meets or exceeds illuminance of 300 lx and 1000 lx

am to 15 pm and 180 working hours from 15 pm to 18 pm respectively. They correspond to 10 % and 7.5 % of total working hours in a year respectively. The same method was applied for 21st June, 23rd September and 21st December. The percentages of annual working hours when illuminance at each measurement point meets or exceeds 300 lx were determined. Finally, the measurement points that meets or exceeds 300 lx at least 50 % of working hours per year were marked on working plane, and ratio of these points to the total measurement points were calculated to achieve sDA value. To calculate ASE, measurement points exposing to illuminance over 1000 lx for more than 250 working hours per year were determined and ratio of these points to the total measurement points were calculated.

Regarding the aspect ratio 2 (12 m depth), the 67 % WWR was found to be the optimum window size achieving the 50.24 % analysis area with sufficient daylight (illuminance over 300 lx) and 13.01 % analysis area exposed to direct sunlight (illuminance over 1000 lx). Daylight levels across the room were decreased due to shading capability of prismatic panels but still remained at an acceptable level.

Regarding the aspect ratio 1.5 (9 m depth), the percentage of area with illuminance above 300 lx was almost halved compared to unshaded room and became 50.99 % when the 43 % WWR was applied.

Regarding the aspect ratio 1 (6 m depth), the configuration with 30 % WWR became the optimum solution, receiving the adequate daylight with the percentage floor area of 56.28 %, Fig. 3.

4. OVERALL ASSESSMENT

- In winter, daylight penetrated deeper into rooms due to the lower position of the sun and illuminance values increased throughout the room.

The prismatic panels were incapable of sun shading during these months and the inclined sun rays passed through between panels led to a considerable increase of illuminance values above 1000 lx. This excessive daylight exposure is also the reason for the high ASE values.

- In summer, the amount of daylight entering the room dropped due to the higher position of the sun. The sun-shading effect of the panels was prominent, since sunlight striking from right angles was reflected by the prism structure. This resulted in a decrease in illuminance values above 1000 lx, which ensures ASE to be within the acceptable range in these months.

- In spring and autumn, the amount of daylight entering the room and the daylight distribution is almost identical. The illuminance values throughout the room are higher than those in summer and lower than those in winter.

- The ratio of the area satisfying 300 lx was calculated regardless of a specific time fraction for a space almost corresponds to the estimated sDA value for this space. Contrary to this, the estimated ASE value is considerably greater than the percentage of the area that meets or exceeds illuminance above 1000 lx, Fig. 4.

- Due to IES requirements, the most satisfying sDA value was found to be 48.54 % in a room of 12 m depth with 67 % WWR. An sDA of 51.59 % and 59.26 % was achieved in a room of 9 m depth with 43 % WWR and 6m depth with 30 % WWR respectively.

- The ASE value obtained for each design alternative exceeded the minimum acceptable ASE of 7 % recommended by IES. The closest ASE values were obtained with the least WWR alternative of 30 % in all room depths. This value was 9.94 %, 13.49 % and 20.99 % in room of 12 m, 9 m and 6 m depth respectively.

5. CONCLUSION

This study would make a contribution to establishing availability of the ‘useful’ daylight, i.e. daylight without over-exposure, in side lighted rooms in terms of improving visual performance, and thus motivation, productivity and well-being of occupants. The current daylighting standards and related previous studies include required window sizes for room geometries, but these are restricted to conventional fenestration systems. However, this study emphasizes that a clear glazing without any daylight system is inadequate to meet the visual performance requirements of the spaces used mostly during the daytime such as educational and office buildings. It has been shown that it is possible to control and use daylight efficiently with the application of advanced daylight systems such as prismatic panels on vertical windows. The consideration of such systems simultaneously with the facade openings in the early design stages is more favourable in terms of avoiding problems related to the amount and distribution of daylight. Therefore, this study suggests new optimal WWR in relation with varying room depths when prismatic panels attached in side windows and recommends rethinking of daylighting requirements mentioned in current daylight standards.

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