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Daylight Factor Analysis with Slat Angle Control for Glare Reduction in a Three Storied Office Building

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Abstract

Estimation of daylight Factor is important to get sufficient, daylight into a room. Window blinds have a large effect on daylight factor. Window blinds slat angle control not only estimates direct solar penetration, but also makes the workplane illuminance within agreeable range. Key findings from the study are window blinds help to control glare, daylighting and overheating. Window blinds control by occupants is an attempt to mitigate building energy use. Slat angle control must be designed effectively to get a good response from occupants. We find that, a slat angle of 15^0 provides uniform illuminance for East, and West facing rooms in Bhubaneswar, Odisha, India.

Keywords: Daylighting; daylight factor; designbuilder; illuminance; sunlight; daylight simulation.

INTRODUCTION

Daylight contributes to sustainable design by reducing glare in a building, and also by improving interior environment. An important strategy for reducing direct solar radiation and glare problems can be window blind control [1]. Window blinds are widely used to maintain occupants visual comfort, and reduce energy use for heating or lighting [2]. Window blinds are a common way of shading, and inaccurate positioning of blinds might fail to give maximum effect of daylight [3].

As required by an occupant, window blinds are controlled more frequently in commercial buildings [4]. Generally, simulation software's provide architectural engineers with design assistance for developing different control options, calibration of desired window blinds control system, and information as to whether one should go for implementation of design or not.

Window blinds control presents an opportunity to better predict daylight factor, and comfort situations to support building design, and operation. Daylight control strategies by shading system, i.e., window blinds have the potential to improve visual comfort [5]. The relationship among sun profile angle, solar azimuth angle and solar altitude angle varies through-out the year. Accordingly, the variation of window blinds' slat angle for different sun positions will give better illumination [6]. Solar energy can penetrate either through windows, or blind slats [7]. Appropriate positioning of slat angles based on orientation, climatic condition, and Window to Wall Ratio (WWR) will provide visual comfort [8].

In this study, window blind control framework is developed by considering different parameters like material, various angles, different floor/zone, and lastly East/ West facing orientation to maximize occupant satisfaction. An office building shown in Fig. 1 is considered for daylight factor analysis. It consists of thirty identical blocks. A single three storey block as shown in Fig. 2 is used in the simulations conducted. Simulation plays an important role to predict the accuracy of a design model. Detailed study for an accurate estimation through simulations lead to design of window blind control. Here slat front view, side view, and different angles of slats are shown in figure 3.

The paper is outlined as follows, Section 2 describes about software tool, and window blind parameters used for simulation. Section 3 describe the different cases simulation results on variation with slat angles and its properties are discussed. The article will conclude with brief concluding remarks and future proposed work are included in section 4 and 5.

Window blind model for daylight analysis

Window blinds are capable of controlling light environment, and indoor temperature. Solar radiation can be controlled by slat type blinds. For direct solar incidence, blinds slat adjustments can redirect light and create shadings. Slats need to be adjusted with changing solar position. When the sun is highest in the sky, direct sun transmission through untreated window is unwanted. Slat angle control addresses the issue of excessive illumination, and occupant visual comfort.

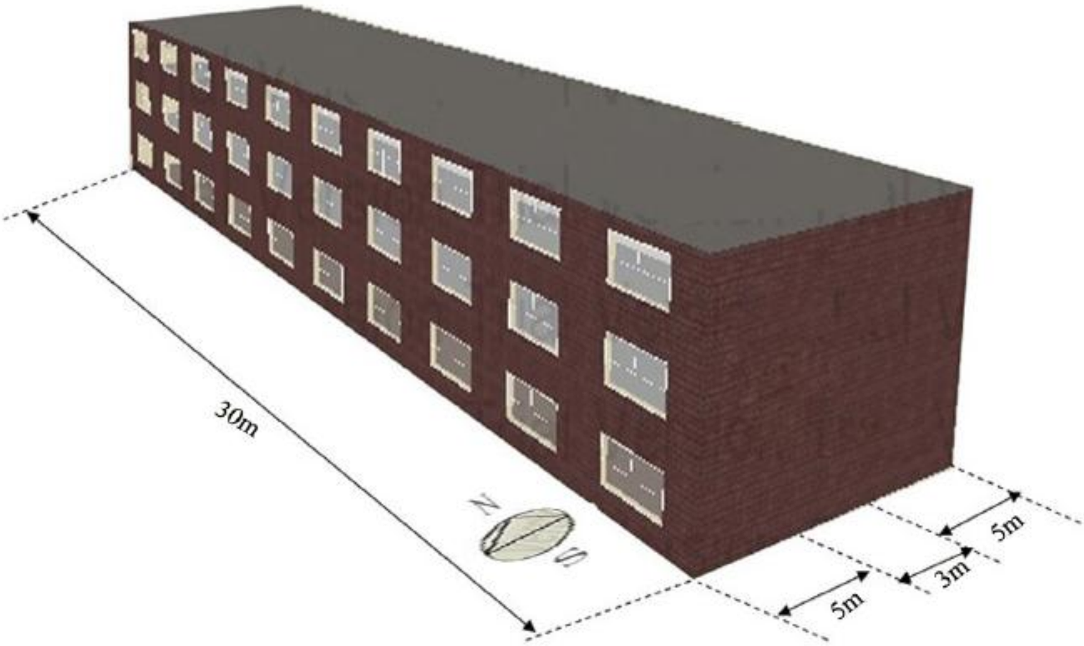

Figure 1. Representation of the whole office building

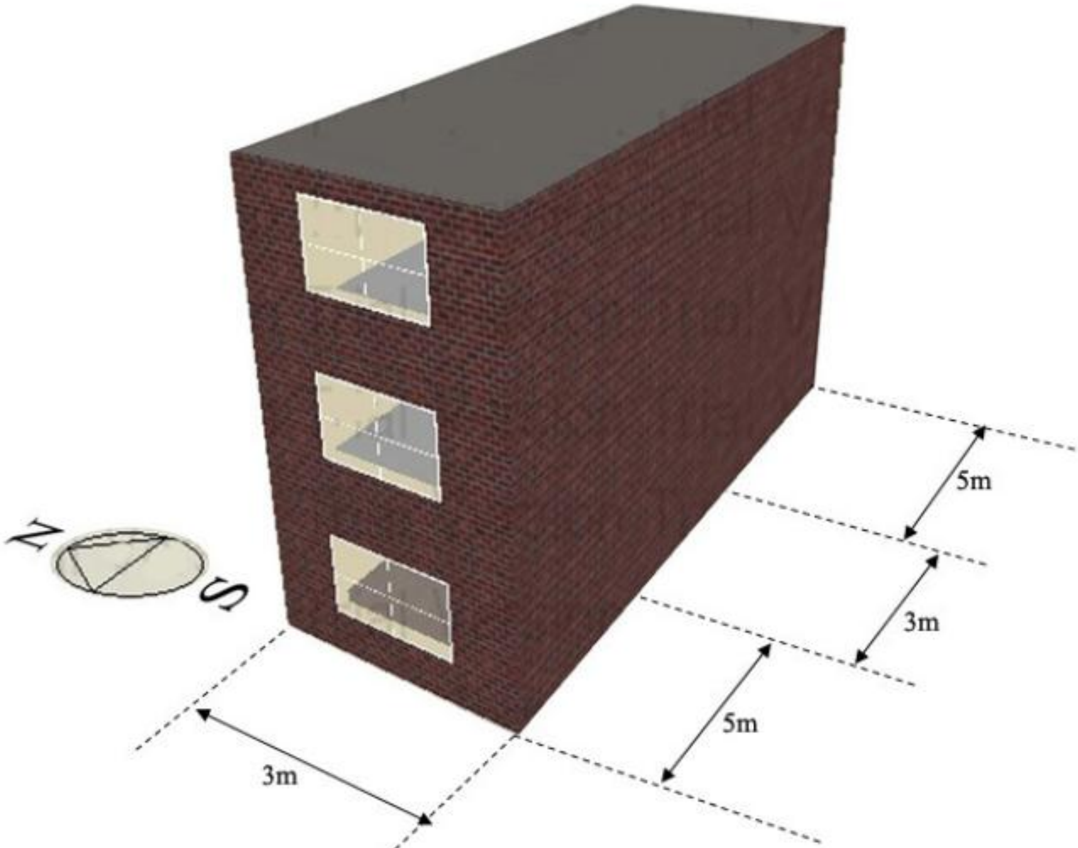

Figure 2. Analysis of three storied floor

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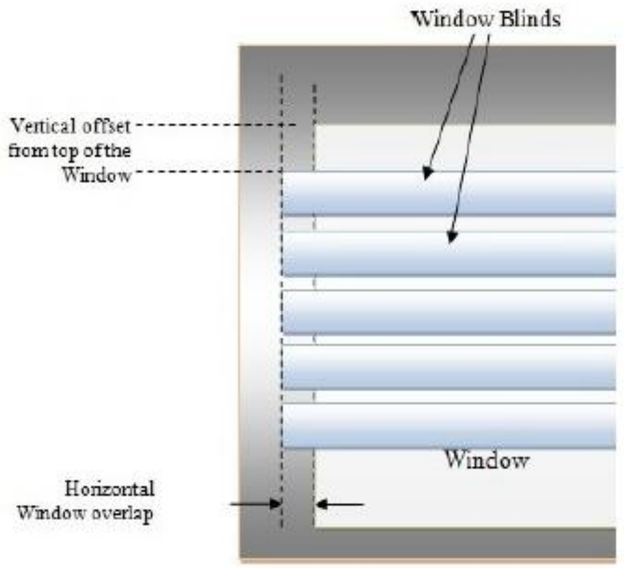
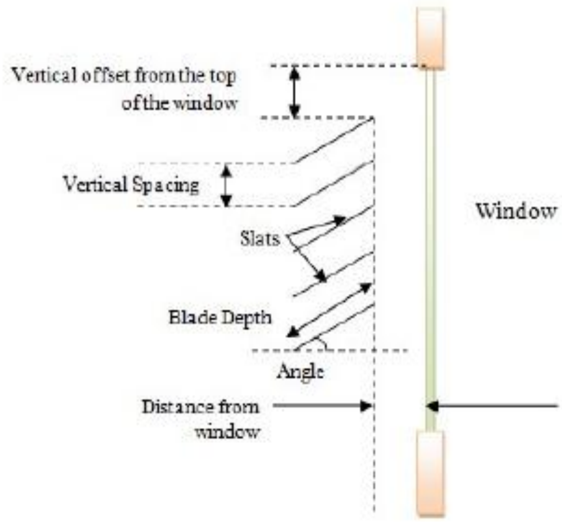
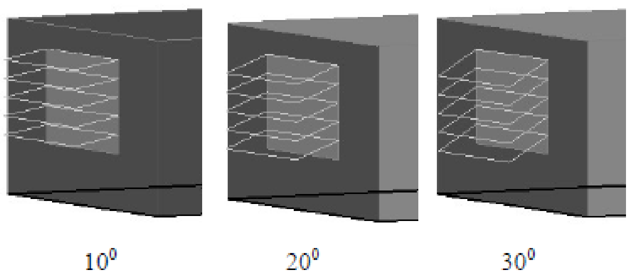


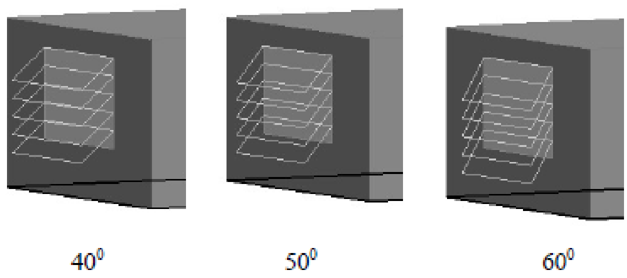
(a) Window blind slat front view



(b) Window blind slat side view



(c) Slat angles



(d) Slat angles

Figure 3: Different possible cases for positioning window blind slats

Software tool

There are many software tools for Daylight Factor (*DF*) analysis in buildings. In this study, DesignBuilder [9] was used as this is user friendly, and is able to simulate complex models.

Discomfort glare index (G) can be calculated [10] by the following expression.

$$G = \frac{L_W^{1.6}\Omega^{0.8}}{L_b + 0.07W^{0.5}L_W} \qquad (1)$$

In the above equation, L_W is average luminance of the window as seen from the reference point (cd/m^2), L_b is luminance of the background area surrounding the wall (cd/m^2), Ω is angle subtended by window, and W is angle subtended by an element in the window.

$$DF = \frac{\epsilon_i}{\epsilon_o} 100\% \qquad (2)$$

In the above expression of Daylight Factor [10], ε_0 is simultaneous outdoor illuminance on a horizontal plane from an unobstructed hemisphere of overcast sky (*lux*), and εi is illuminance due to daylight at a point on the indoor working plane (*lux*).

If $G > 31$, lighting levels are intolerable to human eyes, and if $G < 18$, light is barely perceptible [11].

Model parameters

Study space dimensions of a room in the building shown in Fig. 1 are shown in Table 1. Simulation parameters in DesignBuilder analysis were set to specific values as shown in Table 2.Adoption of Usage of Natural daylight resource concept is still in its natal stage. Small variation in slat angles can help a smart city mission by glare protection. For this, we choose Bhubaneswar area for analysis.

Material specifications

Choosing a proper material is very important before implementing the slats because material properties affect the performance remarkably. It becomes a fixed factor after implementation since it cannot be varied frequently. Hence, it is essential to know the objective of the design. Then only one can decide what type of material should be used. Usually slats are made of aluminum, other metals, wood, glass, polymers, fibres, etc.

Table I. Study Space Dimensions

Parameter	*Value*
Floor area	15 (m^2)
Working plane level	0.85 (m)
Lintel level	2.1 (m)
Window height	1.25(m)
Window width	1.8 (m)

Table II. DesignBuilder analysis parameters

Location	***Bhubaneswar latitude, 20.25 and longitude, -85.83***
Orientation	***East Facing***
Room Dimension	***3(m) *5 (m)*2.8(m) (Width * Depth * Height)***
Time	***March 21***
Condition	***CIE Overcast Sky***
Type	***Illuminance (lux)***

Table III. Details of parameters used in window blinds

Parameter	*Value*
Material thickness	0.0020
No of blades	5
Slat Spacing (m)	0.300
Slat depth (m)	0.800

Table IV. Simulation results for different slat materials

Sr. No.	*Material for Window*	S_{abs}	V_{abs}	*Block 1*			*Block 2*			*Block 3*		
				Z1	*Z2*	*Z3*	*Z1*	*Z2*	*Z3*	*Z1*	*Z2*	*Z3*
1	Sodalime glass	0.7	0.7	0.05	0.04	0	0.04	0.03	0	0.06	0.04	0.01
2	PVC	0.7	0.7	0.05	0.03	0	0.04	0.03	0	0.06	0.05	0.01
3	PC	0.7	0.7	0.05	0.04	0	0.05	0.04	0	0.05	0.04	0.01
4	Stainless Steel	0.2	0.2	0.05	0.04	0	0.05	0.04	0	0.06	0.06	0.01
5	Fiber board	0.6	0.6	0.06	0.03	0	0.04	0.04	0	0.05	0.05	0.01
6	No Blind	-	-	0.33	0.09	0	0.34	0.13	0.01	0.36	0.19	0.01

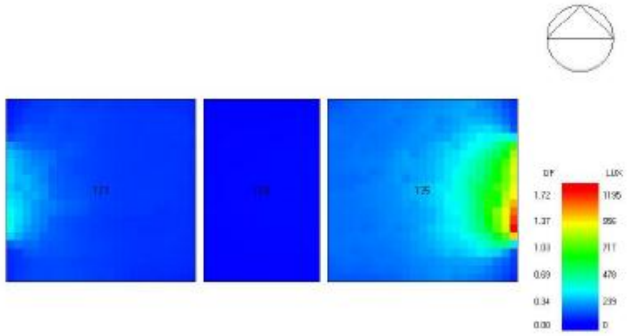
The effect on illumination of different physical and chemical properties, such as opacity, transmitivity, thermal and chemical resistance, solar absorbance, reactivity etc is to be analyzed. These materials can be categorized as metal/non-metal, organic/ inorganic, transparent/ opaque, and so on.

Various types of materials were used in the study space model in Design-Builder Analysis. Table 3 shows properties and values that are used in the simulation for stainless steel. The reason for choosing stainless steel as a material here is due to its high reactance, which has a significant effect on lighting levels [12].

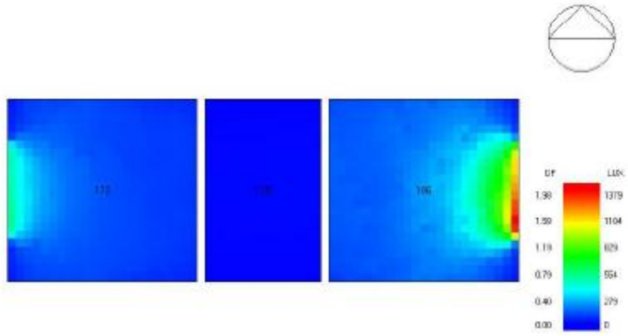
Edge to edge measurement is known as slat width. In principle the optical properties of such components closely relate to its material composition. Modern slats can be made of aluminium, metal, wood, glass or any other material. Their tilt angle can be varied with a metal lever, pulleys, or through motorized operators. There is a variety of options to control the effect of blinds. The physical structure (i.e. slat parameters, slat orientation etc), and the material properties of the blinds are some vital elements which affect the indoor energy accumulation. Different aspects like thermal comfort, and uniformity level of daylighting can be controlled.

RESULTS

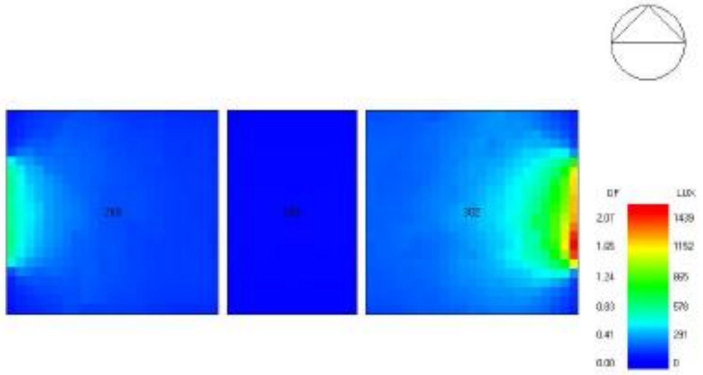
Excessive and improper exposure of daylighting may result in glare and visual discomfort [13]. Movable shading system is more effective than fixed shading system [14].



(a) Case 1 for ground floor



(b) Case 2 for first floor



(c) Case 3 for second floor

Figure 4: Daylight illumination for different floors

Simulation results corresponding to different window slat materials are shown in Table 4. The simulation results for east face are represented as Z1, and for west facing as Z2. Z3 represents the corridor of the building where daylight can not penetrate as it is blocked by interior walls. In our study, Block 1 represents ground floor, Blocks 2 and 3 represent first, and second floor of the building. Solar absorbance and Visible absorbance are denoted as (S_{abs}) and (V_{abs}) in Table 4.

Variation with window mounting position

From simulations (Table 4) we find that second floor will be more illuminated as compared to first and ground floor even if each floor will have the same window size. Window height plays an important factor on *DF*. Higher windows allow more *DF* into a room. From the simulation results we find the maximum illumination values for ground, first, and second floors are 1195 lux, 1379 lux, and 1439 lux respectively.

Table V. *DF* simulation for different slat angles of investigated room at 9am.

	Block1			***Block2***			***Block3***		
Slat Angle	***Z1***	***Z2***	***Z 3***	***Z1***	***Z2***	***Z 3***	***Z1***	***Z2***	***Z 3***
10 deg	0.07	0.03	0	0.06	0.03	0.01	0.08	0.05	0.01
15 deg	0.06	0.03	0	0.06	0.04	0	0.08	0.05	0
20 deg	0.08	0.02	0	0.06	0.04	0	0.08	0.04	0
25 deg	0.08	0.01	0	0.07	0.03	0	0.08	0.04	0
30 deg	0.07	0.01	0	0.08	0.02	0	0.08	0.03	0
35 deg	0.07	0.01	0	0.07	0.02	0	0.07	0.03	0
40 deg	0.06	0.01	0	0.05	0.01	0	0.06	0.02	0
45 deg	0.04	0.00	0	0.04	0.01	0	0.05	0.01	0
50 deg	0.04	0.00	0	0.04	0.01	0	0.04	0.01	0
55 deg	0.03	0.00	0	0.03	0.01	0	0.04	0.01	0
60 deg	0.03	0.00	0	0.02	0.01	0	0.02	0.01	0

Table VI. *DF* simulation for different slat angles of investigated room at noon.

	Block1			***Block2***			***Block3***		
Slat Angle	***Z1***	***Z2***	***Z 3***	***Z1***	***Z2***	***Z 3***	***Z1***	***Z2***	***Z 3***
10 deg	0.05	0.06	0.01	0.04	0.05	0	0.04	0.05	0
15 deg	0.05	0.05	0	0.04	0.05	0	0.05	0.05	0
20 deg	0.04	0.05	0	0.04	0.05	0	0.06	0.06	0
25 deg	0.04	0.04	0	0.04	0.04	0	0.05	0.04	0
30 deg	0.04	0.04	0	0.03	0.04	0	0.04	0.04	0
35 deg	0.03	0.03	0	0.03	0.03	0	0.04	0.04	0
40 deg	0.02	0.02	0	0.03	0.03	0	0.03	0.03	0
45 deg	0.02	0.02	0	0.02	0.02	0	0.02	0.02	0
50 deg	0.02	0.01	0	0.02	0.02	0	0.02	0.01	0
55 deg	0.01	0.01	0	0.01	0.01	0	0.02	0.02	0
60 deg	0.01	0.01	0	0.01	0.01	0	0.01	0.01	0

Table VII. *DF* simulation for different slat angles of investigated room at 3pm.

	Block1			***Block2***			***Block3***		
Slat Angle	***Z1***	***Z2***	***Z 3***	***Z1***	***Z2***	***Z 3***	***Z1***	***Z2***	***Z 3***
10 deg	0.03	0.11	0	0.03	0.08	0	0.04	0.09	0.01
15 deg	0.02	0.08	0	0.03	0.08	0	0.03	0.09	0
20 deg	0.02	0.11	0	0.04	0.08	0	0.05	0.08	0
25 deg	0.02	0.08	0	0.03	0.08	0	0.04	0.10	0
30 deg	0.01	0.07	0	0.03	0.07	0	0.03	0.09	0
35 deg	0.01	0.06	0	0.02	0.06	0	0.03	0.07	0
40 deg	0.01	0.04	0	0.02	0.06	0	0.03	0.06	0
45 deg	0.01	0.03	0	0.01	0.04	0	0.02	0.05	0
50 deg	0.01	0.03	0	0.01	0.04	0	0.01	0.04	0
55 deg	0.01	0.02	0	0.01	0.02	0	0.01	0.03	0
60 deg	0.00	0.02	0	0.01	0.02	0	0.01	0.03	0

Variation with window slat material

In this study, we have tested five different slat materials namely sodalime glass, stainless steel, pvc, pc, and fiber board. Out of these, stainless steel slats give better illumination for each floor of the building as shown in Table 4.

Variation with slat angles in the window

Figure 3 shows that slat angles of window blinds can be varied. Simulations are carried out for different angles to find maximum illumination. From results it is found that 15^0 slat angle gives good illumination in both East and West facing rooms for morning, afternoon as well as in evening.

Variation with season

All the simulations are carried out (without any obstruction) in summer. These results would vary for other seasons, with a reduction in *DF*. Obstructions to sunlight outside the building would further reduce the *DF*.

DISCUSSIONS

The daylighting performance was investigated through simulation for East and West facades of a building in hot climate (march 21). Slat angle control varies according to window to wall ratio, orientation, and seasons. From all the simulations, we can say that *DF* improves in higher oors, slat materials also contribute to change in *DF*, and slat angle control can be very helpful for East facing windows, but are not helpful for West facing windows.

CONCLUSION

As shown in Tables 5,6, and 7 we conclude that some specific angles give good daylight levels for all (morning, afternoon, evening) times. The paper may provide guidance for better design by examining different *DF* values. This study has demonstrated innovative and immediate solution for glare control as well as visual comfort in designing buildings through simulations.

The paper also describes the window slat angle configuration for providing better daylight and visual comfort. This solution shows good performance in terms of glare reduction and comfort level of work where high visibility is desired. For daylight provision and glare protection, window slats have the unique advantage of angle variation. At the same time the required amount of outside view also depends on slat angle variation.

Depending upon the building function, the aspects of the occupants, and varying climate condition, the threshold condition may vary. Supervisory control is required as light levels vary from time to time. The architecture of the building should be so designed to meet both the energy optimization as well as the threshold comfort level of the user.

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