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Observations on Performance of Commonly Used Shading Devices in Tall Office Buildings of Dhaka

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Abstract
Solar radiation is a major source of heat gain for building in the tropics. Large vertical surfaces of tall buildings are exposed to solar radiation and needs to be controlled in view of generating desirable indoor environment. Solar shading is one among the many strategies in dealing with overheating problem in a tropical city like Dhaka. External shading device is the most efficient solar control as it cuts off solar radiation before reaching the window. This paper presents a simulation study of evaluating performance of shading devices on windows in the context of Dhaka (Latitude 23.5°N). Six selected shading devices were evaluated based on percentage of shaded area on windowpane and energy saving potential of shading devices. Simulation results showed that the design of the shading devices need to be explored for desired performance. The results also indicated that depth and spacing of overhangs as well as depth, spacing and angle of vertical fins have significant effect on shading performance. Modification of these parameters may make the shading devices effective in different orientations at the desired periods.

Key words: Performance evaluation, Tall buildings, Solar heat gain, Shading devices, Simulation study, Dhaka City and Tropics.

1. Introduction

The trend of recent development has shifted from low to high-rise buildings due to the pressure of population in much of the world, and Dhaka is no exception. Dhaka is the fast growing capital city of Bangladesh. In 2004 it had an estimated population of 14.34 million (STP report 2005) and every year the city is adding more than 400,000 people to its population. With such a growth scenario, Dhaka has become the center of commerce and economy in Bangladesh. Due to increase in demands for working spaces, high-rise office buildings have evolved. The facades or envelopes of these tall buildings are subjected to a large amount of climatic impact. The recent construction of tall office buildings in urban areas of Dhaka is characterized by extensive use of glass. They have been designed without any respect to the interdependence between outdoor and indoor climate (Ahmed 2003). The common practice now is to provide an envelope which is aesthetically more pleasing rather than climatically responsive. To 'extrude' is the current trend of high-rise development in the context of economic sustainability but the environmental sustainability and energy issues are left unanswered. Architects are often inspired by design ideals from temperate climates that poorly suits with local conditions.

Fenestration and building envelope design has been found to be the most significant factor affecting energy use in high-rise buildings in the tropics (Muhammad *et al* 2005). Vast vertical surfaces of tall buildings are exposed to solar radiation and glass facades may act as heat trap for incoming solar radiation. So facades of tall buildings need protection in view of generating desirable indoor environment. The thermal effect of a glazed wall section depends on the shading provided and the spectral properties of glass (Givoni 1969). Shading the glass affects the quality of incident radiation and hence modifies both the heat flow to the interior and resultant impact to the indoor temperature. Shading device may perform a variety of functions: controlling heat gains either constantly or selectively (eliminating the sun in over heated periods, admitting it in under heated periods). But at present, there is only little consciousness regarding the thermal characteristics of shading devices and the effect of sun shading in Dhaka.

Because of limited of energy resources, ever increasing energy prices and the global warming, the necessity to reduce the energy consumption in the buildings is an important issue in a developing country like Bangladesh. In such a context the need to develop passive means of solar control is important and efficient design of shading devices may address this issue significantly.

A dynamic computer simulation program named 'Ecotect' (version 5.20) has been used for this simulation study to examine the existing shading devices in terms of their performance in reducing solar heat gain.

2. Aims & Objectives

The study is an attempt to investigate the performance of commonly applied shading devices on facades of tall office buildings as a method of passive cooling with the following objectives:

1. To evaluate the existing shading devices as solar control tools used in tall office buildings.
2. To develop an understanding regarding issues relevant to shading design in office buildings of Dhaka.

3. Tall Building: Definition and Criteria

The experts differ in defining the physical parameters of tall buildings. According to the Council for Tall Buildings and Urban Habitat (CTBUH), a tall building is not strictly defined by the number of stories or its height. It also depends upon the context in which it stands. CTBUH defines tall buildings as a building whose built form, by virtue of its height, requires its own special engineering systems (Yeang, 1997). The important criterion is whether or not the design, use or operation of the building is influenced by some aspects of tallness.

David Fisher defines the tall buildings as 'We build tall buildings of necessity; how we build them is a reflection of society. Tall buildings do not have to be beautiful, they simply must be functional; so it is the degree of our concern for their beauty that serves as a measure of our humanity' (Attia, 1990).

According to Ken Yeang (Yeang, 1997), a tall building can be characteristics by

a) A small foot-print in comparison to its total built-up space
b) Tall facades due to its height
c) Small roof-area in comparison to external-wall area
d) Special engineering systems, different from the low building type simply because of its height.

According to Taranath, to define tall building from structural aspects, from structural design and construction point of view, it is simpler to consider a building tall when its structural analyses and design are in some way affected by the lateral loads (Taranath, 1998).

Although there is no fixed parameter of height to denote tall and high-rise building, in view of the considerations stated below, buildings above six storeys may be considered as tall buildings in the present context of Dhaka city.

a) Walk up limit / provision for lift:
    - According to Building construction rules (2006), buildings of seven storied and above in height shall have provision for lift.
    - According to Bangladesh National Building Codes (1993), lifts shall be provided in buildings more than six storied or 20m in height.

b) Fire escape provision:
    - According to Fire Service and Civil Defence rules, buildings of seven storied and above in height shall have provision for Fire escape/ alternative staircase.

4. Solar Heat Gain

The heat gain in a building by radiation from the Sun depends upon the following factors (McMullan, 1992):

- The geographical latitude of the site, which determines the height of the Sun in the sky.
- The orientation of the building on the site, such as whether rooms are facing south or north.
- The season of the year, which also affects the height of the Sun in the sky.
- The local cloud conditions, which can block solar radiation.

- The angles between the Sun and the building surfaces, because maximum gain occurs when surfaces are at right angles to the rays from the Sun.
- The nature of the window glass and whether it absorbs or reflects any radiation.
- The nature of the roof and walls, because heavyweight materials behave differently to lightweight materials.

Solar radiation falls on a surface varies throughout the day and the year. Most solar heat gain to buildings is by direct radiation through windows. The maximum gains through south-facing windows tend to occur in pre-monsoon and post-monsoon period when the lower angle of the Sun causes radiation to fall more directly onto vertical surfaces. The solar heat gain for a particular building at a specific time are relatively complicated to calculate, although it is important to do so when predicting summer heat gains in commercial buildings.

The solar radiation falling upon a clear glass surface is reflected, absorbed and transmitted in proportions similar to those indicated in Figure 1. These quantities depend upon the angle of incidence (i) and the proportion of direct and diffuse radiation. The angle of incidence (i) is the angle measured between the incident light beam and the normal to the plane of the glass (Smith, 1982).

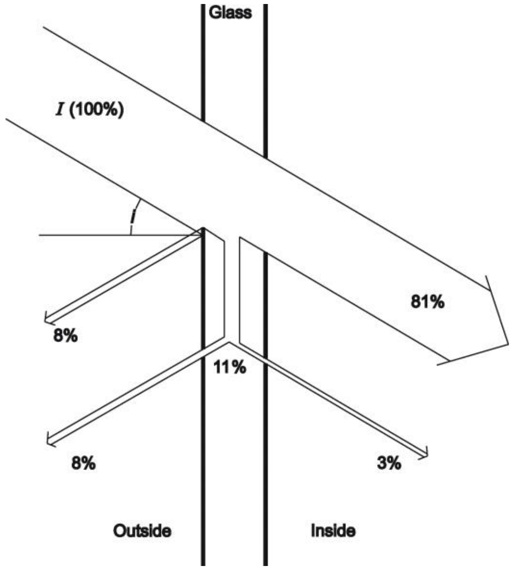


Figure 01: Typical proportions of incident solar radiation, reflected, absorbed, transmitted and retransmitted by glass *(Source: Smith, 1982)*

The absorbed radiation heats the glass and part of this heat reaches the room surfaces by convection and radiation from the inside surface of the glass. The solar heat gain is obtained by adding this inwards released heat to the directly transmitted component of the incident solar radiation. Absorption of this solar heat gain by the internal surfaces raises their temperature. These heated surfaces behave as low temperature, long wave radiators. Since glass transmits shortwave radiation in the range 0.3 to 2.8 μm but is opaque to long wave radiation from low temperature surfaces, the solar heat gained is trapped within the enclosure causing an internal temperature rise. This phenomenon, frequently referred to as the greenhouse effect, may give rise to solar overheating. Heat gain is directly proportional to the area of glass exposed to solar radiation and therefore large glazed areas will permit a large and rapid heat gain.

5. Performance Evaluation Process

The performance of shading devices and its impact on solar heat gain through windows can precisely be evaluated by simulation study. In reality, due to the simultaneous influence of many different conditions, it is difficult to isolate the exclusive effect of one single aspect or the changes of it. Shadow simulation allows study of the effect of changes in one aspect, keeping other factors constant. The observations of simulated behaviour that occurs due to changing parameters allow the identification of elements, the reduction or introduction of which in the design contribute to solar heat gain. Another significant aspect of simulation study is that, it is possible to analyze the performance of shading devices for any period of the year simply by modifying simulation parameters (e.g. temperature, radiation, wind speed and direction, relative humidity and cloud cover).

Evaluation process comprises the following steps:

- Selection of Shading Devices
- Setting criteria for performance evaluation
- Preparing climate database
- Setting simulation parameters
- Developing simulation model
- Analysing results of simulation

5.1 Selection of Shading Devices

Before making selection of shading devices, tall office buildings are identified on the basis of certain considerations to be discussed in the following section. These tall office buildings are located in different commercial areas in the Dhaka city, such as Motijheel, Dilkusha, Karwan bazaar, Panthapath, Banani and Mohakhali. After that, buildings were categorised considering the typology (based on geometry) of shading devices installed on their front façade. Sketches of window sections with shading device of these buildings were prepared with detail construction features, installation technique and geometric features. After analysing the sketches, six shading devices were selected to evaluate performance in terms of reducing solar heat gain considering shading device typology and similarities in geometric features.

Eighty-four tall office buildings of Dhaka city were identified for investigation. Among them, forty buildings are situated at Motijheel and Dilkusha area; twenty-four buildings at Mohakhali, Gulshan Avenue and Banani Kemal Ataturk Avenue; fourteen buildings at Karwan Bazaar area and six buildings at Panthapath. Among these eighty-four tall office buildings, six buildings were selected to evaluate performance of their shading devices. The list of buildings with location, storey, orientation and type of shading device installed is presented below:

Table 01: List of the selected buildings and shading devices

Sl No.	Identification Number	Location	Storey	Orientation	Shading Device
1	H01	Global Insurance Ltd. Dilkusha	11	South	Horizontal
2	H02	Janata Bank Bhaban, Motijheel	23	South	Horizontal
3	H03	Brac Center, Mohakhali	20	South	Horizontal
4	V01	Rupali Bank Ltd, Dilkusha	10	West	Vertical
5	V02	Ispahani Bhaban, Dilkusha	9	West	Vertical
6	V03	Bangladesh Samobye Bhaban, Motijheel	9	East	Vertical

5.2 Criteria for Performance Evaluation

In order to evaluate the performance of shading devices in reducing solar heat gain, a base-case situation is established by studying the unshaded window (without shading device) during the critical shading period of the year at different orientations. From the literature review it is found that the percentage of the shade area and the shading coefficient are two primary critetia of shading performance to determine ability of a fixed shading device in terms of reducing solar heat gain.

a. **The percentage of the shaded area:** The percentage of the shaded area, given by various types of fixed shading devices is one of the criteria of shading performance (Givoni, 1969; Steemers *et al,* 2002). The percentage of the shade areas refers to portion of the window area, which is not exposed to the direct solar radiation. Heat gain is directly proportional to the area of glass exposed to solar radiation. This also reflects the ability of a fixed shading device to protect the window area at critical time.

b. **The shading coefficient:** Computation of the shading coefficient, which is the ratio of the heat entering the window-shading combination to that entering an unshaded window, is another criteria of shading performance. Shading coefficients basically refer to the fraction of solar heat gain that passes through a transparent solar aperture compared to the amount of solar radiation incident upon it. The shading coefficient is expressed as a dimensionless number from 0 to 1. A high shading coefficient means high solar gain, while a low shading coefficient means low solar gain (Givoni, 1969; Givoni, 1998; Steemers *et al*, 2002; Lechner, 2001). Shading coefficient (C_{sh})can be expressed as below.

$$C_{sh} = \frac{\text{Heat entering through the window with shading device}}{\text{Heat entering through the window without shading device}}$$

From energy saving point of view, shading coefficient should be '0' and shading percentage of shaded area should be 100% for optimum performance.

5.3 Simulation Parameters

To investigate the results of the simulations, a specific day has been selected (from the weather database for the year 2005) on the basis of some specific attributes to observe the results.

The test day is 21st of March (Day: 80). Outdoor air temperature range of this day is 24.5ºC -35.4ºC and sky condition is clear. From 0900-1700 hours the cloud cover is 1.1 out of 8.0 (13.8% coverage). This is a day with considerable high outdoor air temperature but not the extreme one and bears a common character regarding the climatic features specially of the hot-dry season. The average temperature of this day (29ºC) is very close to the average temperature of the season (28.02ºC). It has been observed that the sky condition in the given climate is clear for 67 percent of the whole pre-monsoon period and the 'clear sky' condition prevail for the chosen day. This 'clear sky' condition of the chosen day is also important to investigate the impacts of solar radiation and this clear sky condition enhances the direct solar radiation to reach the building surfaces. Fixed shading device are effective to reduce heat gain from direct solar radiation (Goulding, 1992).

For a fixed shading device, the shading period is symmetrical about June 21. This is because the position of the sun cycles, relative to earth, through the sky on a seasonal basis. Thus, the sun will pass through the same path twice every year, the first time when going from winter to summer and the second time when traveling back to winter. Thus, any shading device will always shade between two dates. In the northern hemisphere, an optimized shading device for the 21st of March will actually shade from the 21st of March, right through June until the 21st of September (Lechner, 2001). Thus the whole overheated period (hot-dry and warm-humid) is taken into account for simulation.

For simulation to investigate the performance of the shading devices, the time period is considered when the space is only considered to be used during office hours. In general, the office time is from 0900 to 1700 and this time period is taken as a critical time period for shading requirement.

5.4 Simulation Program

Simulations regarding solar performance analysis are carried out using building analysis software 'ECOTECT v5.20'. It features a user-friendly 3D modelling interface fully integrated with a wide range of performance analysis and simulation functions. The visual nature of calculation feedback makes 'ECOTECT' unique.

The original 'ECOTECT' software was written as a demonstration of some of the ideas presented in PhD thesis by Dr. Andrew Marsh at the School of Architecture and Fine Arts at The University of Western Australia. The software has undergone some major changes since then. Version 5.2 builds significantly on the functionality of previous versions introducing a range of new analysis functions and real-time hidden line and sketch visualization.

ECOTECT provides a range of thermal and solar performance analysis options. At its core, is the Chartered Institute of Building Services Engineers (CIBSE) Admittance Method used to determine heat loads. The Admittance Method is widely used around the world and has been shown to be an extremely useful design-tool. This thermal algorithm is very flexible and has no restrictions on building geometry or the number of thermal zones that can be simultaneously analyzed. Most importantly, with only a few pre-calculations for shading and overshadowing, it is very quick method to calculate and can be used to display a wide range of very useful information.

Whilst in summary it is a simplified method, the Admittance Method encapsulates the effects of conductive heat flow through building fabric, infiltration and ventilation through openings, direct solar gains through transparent materials, indirect solar gains through opaque elements, internal heat gains from equipment, lights and people and the effects of inter-zonal heat flow.

5.5 Climate Database

The climate database stores files containing hourly weather data. The weather files supplied with Ecotect cover different regions of the world and each represents a typical year's weather for a particular region. The weather file for

Dhaka is not provided with the software. But facilities are provided to allow creating own weather files and can be added to the climate database.

The weather file 'Ban_Dhaka.wea' has been prepared for the research purpose by using the Weather Tool, associated software of Ecotect. The Weather Tool is a visualization and analysis program for hourly climate data. The weather file consists of a group of parameters relating to the weather site and hourly values of seven weather variables (dry-bulb temperature, relative humidity, direct radiation, diffuse radiation, wind speed and direction and cloud cover). Hourly radiation data has been collected from Renewable Energy Research Centre of Dhaka University. Three hourly weather data regarding dry-bulb temperature, relative humidity, wind speed and direction and cloud cover has been collected from Climate Division, Bangladesh Meteorological Department Agargaon, Dhaka. Due to the simulation requirements, all three hourly data have been converted to hourly data by interpolation method. Hourly weather variables for Dhaka have been collected for the year 2005.

The site parameters of Dhaka for weather file are as follows:

Parameters	**Details**
Latitude (degrees North)	23°50' North
Longitude (degrees East)	90°20' East
Time Zone (hours ahead of GMT)	GMT +06.00

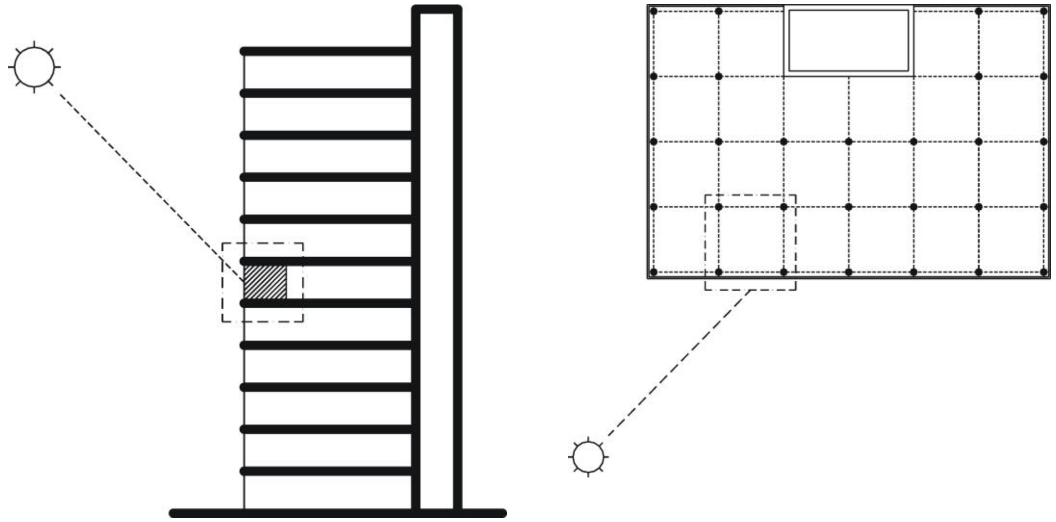
The combination of site parameters and hourly weather variables forms the weather file, with which the simulation program 'Ecotect' is capable to analyse any climatic characteristics of the selected site.

5.6 Simulation Model

Following models (Figure 03b-08b) have been developed for simulation that represents the selected shading devices. These models refer to the high-rise buildings selected with identical single glazed clear glass facades with similar shading devices. The room size for simulation model is 6000mm x 6000mm which is considered to be located at an intermediate floor of a high-rise building. The room size is taken from the typical high-rise column grid. A fixed window width 5400mm has been considered with single glazed glass, as the window covers the whole span between two columns (Figure 02). Different shading devices are attached on it for simulation study. For the ease of calculation, a study plane at the level of the exterior surface of the window wall has been observed.

In terms of shading analysis and solar heat gain, the simulations are done for the following options of models:

- The 'without shading' option - which refer to the high-rise models with identical facades without the shading device but with clear glass;
- The 'with shading' option which refer to the high-rise models with shading as designed by the architect.



(a) Section of typical high rise building

(b) Typical floor plan of high rise building

Figure 02: Schematic drawings showing generation of simulation model from typical high rise building

The simulations are done for the following models generated by 'Ecotect':

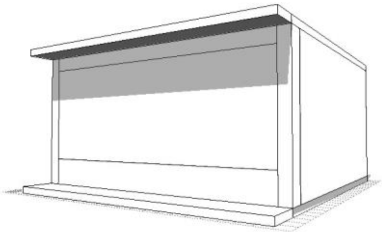
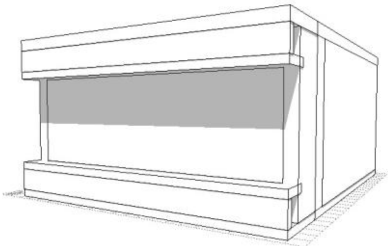
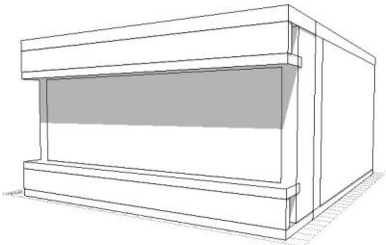
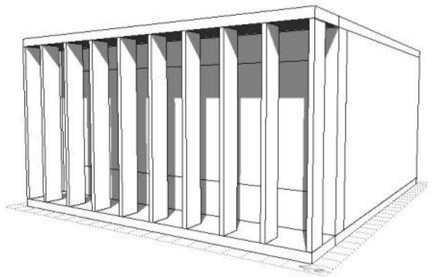
	 **Building Parameters:** • Office room dimension: 6000mm x 6000mm • Floor height: 3000mm • Window: Orientation: South Sill: 600mm, Width: 5400mm, Height: 2100mm • Overhang depth: 750mm
Figure 03(a): View of building H01	**Figure 03(b):** Simulation model of Shade H01
	 **Building Parameters:** • Office room dimension: 6000mm x 6000mm • Floor height: 3000mm • Window: Orientation: South Sill: 600mm, Width: 5400mm, Height: 1800mm • Overhang depth: 450mm
Figure 04(a): View of building H02	**Figure 04(b):** Simulation model of Shade H02
	 **Building Parameters:** • Office room dimension: 6000mm x 6000mm • Floor height: 3000mm • Window: Orientation: South Sill: 750mm, Width: 5400mm, Height: 2400mm • Overhang depth: 450mm
Figure 05(a): View of building H03	**Figure 05(b):** Simulation model of Shade H03

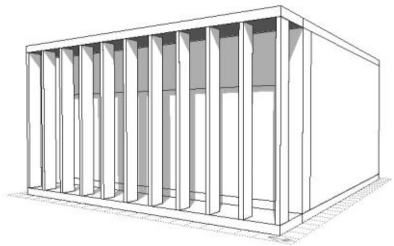
Figure 06(a): View of building V01



Building Parameters:
- Office room dimension: 6000mm x 6000mm
- Floor height: 3000mm
- Window: Orientation: West
  Sill: 600mm, Width: 5400mm, Height: 1950mm
- Vertical Fin: Depth: 375mm, Spacing: 600mm

Figure 06(b): Simulation model of Shade V01

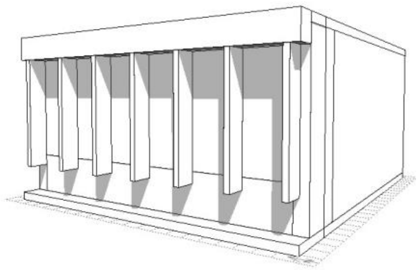
Figure 07(a): View of building V02



Building Parameters:
- Office room dimension: 6000mm x 6000mm
- Floor height: 3000mm
- Window: Orientation: West
  Sill: 600mm, Width: 5400mm, Height: 1950mm
- Vertical Fin: Depth: 300mm, Spacing: 600mm

Figure 07(b): Simulation model of Shade V02

Figure 08(a): View of building V03



Building Parameters:
- Office room dimension: 6000mm x 6000mm
- Floor height: 3000mm
- Window: Orientation: East
  Sill: 600mm, Width: 5400mm, Height: 1950mm
- Vertical Fin: Depth: 450mm, Spacing: 600mm

Figure 08(b): Simulation model of Shade V03

6. Simulation Results

To evaluate the shading performance on the basis of set criteria discussed earlier, a comparative analysis among the selected shading devices has been summarized in the following section.

6.1 Shading Performance of Horizontal Shading Devices

Table 02 shows the percentage of shaded area of windowpane by three selected horizontal shading devices. At south orientation, all three shading devices were capable to shade maximum area of window pane at mid day. The percentage of shaded area decreased along as time passes before and after mid day (Figure 09). Simulation results show that among the three horizontal shading devices, Shade H01 can shade maximum 60% of the whole windowpane, Shade H02 can shade maximum 53% and Shade H03 can shade maximum 46% of the whole windowpane.

Table 02: Percentage of shaded area at South orientations by horizontal shading devices for 21st March

Orientation	Shading	09:00	09:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00	15:30	16:00	16:30	17:00
		%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
South	H01	52	54	53	56	56	55	60	53	56	57	54	55	52	50	48	42	38
	H02	45	46	47	51	50	50	53	48	52	49	46	45	42	41	36	29	25
	H03	39	41	45	42	41	44	46	40	44	39	36	43	39	38	38	30	28

Table 03 presents the amount of direct solar radiation received by the shading devices and also shows shading coefficient of respective shading devices. From table 2 it is found that at south orientation, Shade H01 can block 3411 watt solar radiation which is 54% of the total incident radiation (6314 watt). If it is compared with other two horizontal shading devices, it is found that Shade H02 can block 46% of the incident radiation and Shade H03 can block 41% of the incident radiation. Highest shading coefficient (0.6) is shown by the Shade H03, while the lowest one was presented by the Shade H01 which was only 0.46. The lower the shading coefficient is better against solar radiation.

Table 03: Amount of direct solar radiation incident on windowpane at South orientations

Orientation	Shade H01			Shade H02			Shade H03		
	Shaded (in Watt)	Unshaded (in Watt)	Shading Co-efficient	Shaded (in Watt)	Unshaded (in Watt)	Shading Co-efficient	Shaded (in Watt)	Unshaded (in Watt)	Shading Co-efficient
South	2903	6314	0.46	3439	6319	0.54	3766	6326	0.60

6.2 Shading Performance of Vertical Shading Devices

Table 04 illustrates the percentage of shaded area of windowpane by three selected vertical shading devices at east and west orientation. At east and west orientation, almost same character of performance of these vertical shading devices has been observed. All three shading devices are capable to shade maximum area of window pane at the time when the sun is just tilted to east or west from south. From table 3 it is observed that at east and west orientations all three shading devices are not consistent in their performance. Sometimes these three shading devices can protect almost 95% of the window area but the efficiency drops frequently to 13%. Considering all these limitations, in comparison with these three vertical shading devices, Shade V01 is capable to shade more areas than other two shading devices.

Table 04: Percentage of shaded area at East and West orientations by vertical shading devices for 21st March

Orientation	Shading	09:00	09:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00	15:30	16:00	16:30	17:00
		%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
East	V01	47	53	78	87	95	*	*	*	*	*	*	*	*	*	*	*	*
	V02	40	48	66	82	94	*	*	*	*	*	*	*	*	*	*	*	*
	V03	38	42	53	58	80	*	*	*	*	*	*	*	*	*	*	*	*
West	V01	*	*	*	*	*	*	*	*	*	89	80	66	42	40	27	16	13
	V02	*	*	*	*	*	*	*	*	*	80	64	50	40	36	31	24	16
	V03	*	*	*	*	*	*	*	*	*	76	64	48	38	36	22	18	14

* Percentage of shaded area is not taken into account as the sun does not see the window

From table 05, it has been found that the ratio of total energy received between shaded and unshaded situation is lowest for V01, while it is highest for V03 at both east and west orientation. Table 4 shows that at east and west orientation, Shade V01 can prevent almost 70% (in average) of the total incident radiation. If it is compared with the other two vertical shading devices, it is found that Shade V02 and Shade V03 can resist 60-65% of the incident radiation.

Table 05: Amount of direct solar radiation incident on window pane at different orientations

Orientation	Shade V01			Shade V02			Shade V03		
	Shaded (in Watt)	Unshaded (in Watt)	Shading Co-efficient	Shaded (in Watt)	Unshaded (in Watt)	Shading Co-efficient	Shaded (in Watt)	Unshaded (in Watt)	Shading Co-efficient
East	1248	3766	0.33	1461	3766	0.39	1443	3763	0.38
West	701	2556	0.27	906	2556	0.35	848	2556	0.33

7. Discussion and Conclusion

The investigation was carried out to understand the impact of external solar shading devices on reducing solar heat gain and to evaluate the performance of commonly used shading devices in reducing solar heat gain. Analysis of the simulation results indicated a clear understanding of the shading parameters and their contribution to the energy consumption. From the comparison of shading percentage and solar radiation gain between options 'with' and 'without' shading device schemes, it has been shown that solar radiation blocked by shading devices offers an opportunity to reduce cooling loads and energy requirement significantly.

Result of the simulation indicates that Shade H01 was able to shade more areas of window with compares to other two horizontal shading devices. Shade H01 also showed low shading coefficient (0.46) which indicates low solar heat gain than other horizontal shading devices. If we look at the geometric parameters of the shading devices (Fig 3b, 4b & 5b), we will find that the ratio of shading overhang to window height is high in case of H01 which is 1:3. For other two shades H02 and H03, it is 1:4 and 1:6. The shading device with higher 'overhang depth and window height ratio' performed better in reducing solar radiation gain. It means 'overhang depth and window height ratio' has a great impact on the performance of horizontal shading devices in solar heat gain. Although Shade H01 was more effective in comparison to Shade H02 and H03, H01 failed to block almost half of the total incident radiation. So projection of this overhang is not effective to protect the window from the solar radiation properly. So, further investigation is needed to find out the required depth of overhang in relation with window height to get optimum result.

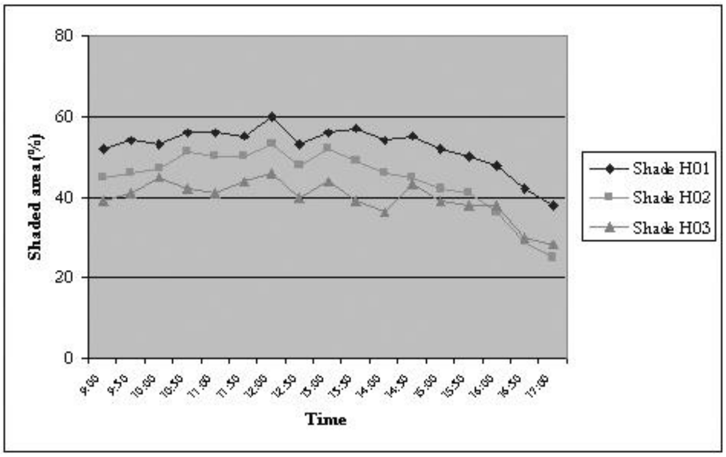


Figure 09: Comparison of percentage of shaded area at South orientation by horizontal shading devices for 21st March

It has been observed from the results of the simulations that the performance of horizontal shading devices remains quite consistent at south orientation only. It works better when the sun is opposite to the window pane at a high altitude. This performance drops when the sun is in a lower altitude and oblique to the window pane. The horizontal overhang is not capable to protect the window when the sun azimuth and altitude are low. Therefore, the sun will outflank an overhang with the same width as window-width. So from these analyses, need for modification of horizontal shading devices is evident when the sun is at low azimuth and altitude. To improve the performance of horizontal shading device at morning and afternoon, the effect of side offset of horizontal overhangs from window edge need to be assessed. Several overhangs on the window pane can be used instead of one large overhang. Installing several overhangs on the window pane is also appropriate when the projecting distance from the wall is limited for structural or other reasons. This could be important if a building is on or near the property line or there are certain restrictions by building regulations.

In case of vertical shading devices, it has been observed from the simulation results that Shade V01 can shade more areas of window than other two shading devices and also shows low shading coefficient (0.33 in east orientation and 0.27 in west orientation) which indicates low solar heat gain. If we analyze geometric parameters of the shading devices, we will find that the V01 is not the deepest one. Although Shade V03 is the deepest vertical fin among the three, it shades less than others. But one thing has to be noticed that the total effective depth of shading device (Fin depth + distance between fin and windowpane) is biggest in case of shade V01 which is 900mm. The shading device with higher effective depth of fin performed better in reducing solar radiation gain. It means effective depth of fin (Fin depth + distance between fin and windowpane) has a great impact on the performance of vertical shading devices in solar heat gain. The depth and spacing of vertical fins is independent of window height and width. The performance of vertical shading devices increases with the increase of depth of vertical fins and with the decrease of spacing between vertical fins.

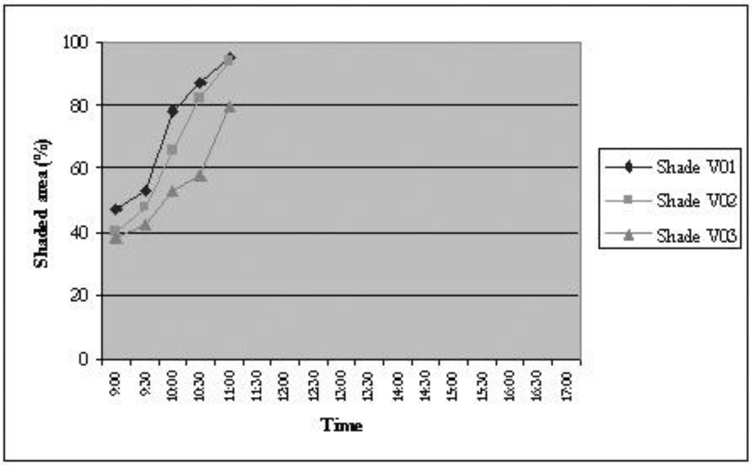


Figure 10: Comparison of percentage of shaded area at East orientation by vertical shading devices for 21st March

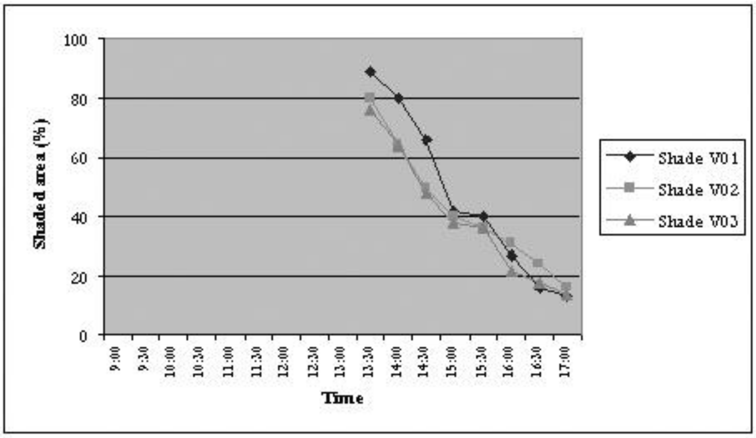


Figure 11: Comparison of percentage of shaded area at West orientation by vertical shading devices for 21st March

The simulation results show that all these three vertical shading devices are capable to shade above 50% of the window area on an average at east and west. They work efficiently when the sun is at an angular position with the window. They are not effective when the sun's altitude is low and perpendicular with the façade. It has also to be noticed that vertical fins are not efficient at east and west orientation when the sun is just in front of the window. This phenomenon needs further investigation. By changing the angle of vertical fin from perpendicular to the window surface to clock-wise direction, the performance of vertical fin may increase. This type of vertical slanted fin can be appropriate either when there is a desire to control the direction of view or when the view is not important. When designing a vertical fin for west facade, one must remember that the sun travels relative to earth from the southwest. Therefore, the sun will outflank a vertical fin with the same height as a window-height. Windows need higher vertical fin extending over the window edge. The extension over the top edge of window depends on spacing between vertical fins.

After investigating the performance of commonly used shading devices it could be stated that the design of the shading device is need to be explored for optimum performance. The results of the simulation study indicate that depth of overhangs and depth, spacing of vertical fins has significant effect on shading performance. Modification of these parameters may make the shading devices effective in different orientations at the critical periods. Designers can evaluate the performance of shading devices in the design stage. Environmental design principles are most effective when considered during the earliest most conceptual stages of the building design process. Geometry, material and siting are three important determinants of overall building performance. Designers can start generating vital performance-related simulation to support for very early stage of conceptual design as well as final design validation. Designers can also do detail climatic analysis to calculate the potential effectiveness of various passive design techniques. The very act of analyzing different options will help the designer about what is likely to work or not work, progressively guiding and refining subsequent decision-making. This work may also instigate designers to design efficient shading devices with a reference to climate issues.

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