International Journal of Environment & Agricultural Science

BIO ACCENT

Avick Sil, Int J Environ & Agri Sci 2017, 2: 1
2: 012

Research

Neighborhood Shadow Analysis of Proposed High Rise in Mumbai, India: A Case Study

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Abstract

Mumbai is the financial capital of India and it attracts many migrants from various part of India because of its business opportunities. Extensive development has already taken place which contributed little availability of land recourses in the prime location of the city. Therefore, most of the builders are concentrating on vertical development rather than horizontal ones. This has lead to concept of high rise developments. But these high rises are developed without taking into account the environmental degradation caused by them. One of the factors is shadow effect from high rises on its neighboring structures. This paper highlights probable effect of shadow on neighborhood structures from a proposed high rise building in Mumbai, India. Not much of difference was observed in terms of shadow effect after the development of proposed high rise. A solar or sunlight rating was developed for neighborhood structures in and around the proposed high rise. Finally this paper provides recommendations that must be considered in order to curb shadow effect from high rise buildings on neighborhood structures.

Keywords: High Rise; Mumbai; Neighborhood Shadow; Neighborhood Structure; Solar Rating

Research Highlights

Sustainable development is the key for urban planning and development. High rise building may cause environmental damage in and around it. This paper highlights shadow impact from a proposed high rise building in a congested area of Mumbai. Some of the major findings were:

Not only the height but also width, breadth and structural design of high rise were the major contributor of shadow

Not only the proposed high rise but also other structures around it contributed equally to neighborhood shadow

Due to presence of two commercial complexes of India bulls, not much difference was observed for shadow with construction of proposed high rise building

Shadow on neighborhood structure depend on height, location and presence of other structures or buildings around it

Shadow from the proposed high rise fell on neighborhood structure for a particular time of the day but during other time they received enough sunlight

Depending on the time for which a structure received sunlight, a solar rating was developed for the neighborhood buildings around a high rise

Introduction

Cities have become centers of growth but they suffer from many issues such as environmental degradation in terms of water pollution, solid waste generation, air pollution and heat island effect. These impacts have continued to put additional burden on the environment infrastructure of cities. Mumbai is a mega city which has become part of these burgeoning issues. It is the financial capital of India and its business opportunities and high standard of living attract migrants from all over India. It has humid climate throughout the year with three distinct seasons' viz., summer, monsoon and rainy [1]. Development of high rise or tall buildings could lead to various direct and indirect environmental impacts. One of these is effect of shadow on environment as well as on neighboring structures in and around the building. Shadow could have impact on green covers, plants, trees, grass, shrubs etc [2]. It could also affect adjoining small structures like residential colonies, corporate offices, shops, shopping malls etc. Shadow analysis is important in order to predict the probable impact of shadow on the environment as well as on human health.

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Sub Date: March 6th, 2018, **Acc Date:** March 6th, 2018, **Pub Date:** March 23rd, 2018.

Citation: Avick Sil (2018) Neighborhood Shadow Analysis of Proposed High Rise in Mumbai, India: A Case Study. Int J Environ & Agri Sci 2: 012.

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Shadow is an area where direct light from a light source cannot reach due to obstruction by any object. It occupies all of the space behind an opaque object with light in front of it. Shadow changes with time, height and length of the structure. It is an important aspect of building design. It enables understanding of the extent to which shadows from local structures affect the neighboring properties. This helps in making decisions regarding placement of parking lots, solar panels, windows, planted areas, green zones, playing/recreational areas, etc [3]. On the other hand, it can produce a great deal of useful information about shape, relative position, surface character and other effect of generating shadow [4]. Length of shadow is dependent on the height of building and its roof top area and in many cases shapes as well [5].

Shadows are longer in the early morning and late afternoon, particularly in winter, when the sun is lowest on its horizon. Therefore, extensive shading in common place is an accepted part of the normal pattern of light during early morning and late afternoon in late fall and early winter, especially in a built-up urban area. Therefore, cumulative shadow impacts would not interfere with any beneficial uses of parks or open space and would not be considered significant. The validity of detected regions as shadows is further verified by making use of more complex hypotheses on color invariance and geometric properties of shadows [6]. Impact of shadow on environment and human health would depend on climatic conditions of that area. Mumbai is a coastal city and it has hot and humid climate throughout the year, humidity ranging between 47% and 86% and annual average temperature of 25 – 35 ^{O}C.

The objective of this study was to predict the probable length of shadow and its impact on neighboring structure from a proposed high rise building in Mumbai. Comparison was made for shadows of different seasons from proposed high rise. Similarly comparison was made for shadows with the current situation (without high rise) and with the construction (existence) of the proposed high rise. Also amount of sunlight received by different structures were also estimated and a rating for the same has been developed. Finally this paper provides recommendations for community development for future high rise projects in terms of shadow impacts.

Methodology

Shadow Prediction

Shadow prediction was carried out with Amethyst ShadowFX version 3.01.15. This software were procured from CA Design Associates Ltd. Shadow prediction depends solar azimuth angle, declining angle, altitude angle and angle of incidence. All these factors were obtained as per the methodology of [7] and they are described below:

Solar Azimuth Angle

Solar azimuth angle is the azimuth angle of the sun. It is calculated by:

$$\sin\phi_s = \frac{-\sin h\cos\delta}{\cos\theta_s}$$

This formula utilize cosine, the azimuth angle is always positive, and therefore, should be interpreted as the angle less than 180^0 when the hour angle, h, is negative in morning and the angle greater than 180^0 when the hour angle, h, is positive in afternoon. Hence it is mostly calculated using the formula:

$$\cos\phi_s = \frac{\cos h\cos\delta\sin\Phi - \sin\delta\cos\Phi}{\cos\theta_s}$$

$$\cos\phi_s = \frac{\sin\theta_s\sin\Phi - \sin\delta}{cos\theta_s\cos\Phi}$$

where:

ϕ_s is the solar azimuth angle; θ_s is the solar elevation angle; h is the hour angle of the present time; δ is the current sun declination; Φ is the local latitude angle

Declination Angle

The equation used to calculate the declination angle on any given day:

$$\delta = 23.45\frac{\pi}{180}\sin\left[2\pi\left(\frac{284+n}{365.25}\right)\right]$$

δ : Declination angle in rad and, n = the day number

Altitude Angle

Altitude angle (α) can be calculated by:

$$\sin\alpha = \sin\delta\sin\phi + \cos\delta\cos\omega\cos\phi$$

Angle of Incidence

The angle of incidence (θ_i) of the sun surface tilted at an angle from the horizontal (β) and with any surface azimuth angle (A_{ZS}) can be calculated from (when A_{ZS} is measured clockwise from north):

$$\cos\theta_i = \sin\delta\sin\phi\cos\beta + \sin\delta\cos\phi\sin\beta\cos A_{ZS} + \cos\delta\cos\phi\cos\beta\cos\omega - \cos\delta\sin\phi\sin\beta\cos A_{ZS}\cos\omega - \cos\delta\sin\beta\sin A_{ZS}\sin\omega$$

This equation can be simplified further for number of scenarios. When the surface is flat (i.e. horizontal surface), β = 0, Cos β = 1, sin β = 0. There the equation becomes:

$$\cos\theta_i = \cos\theta_Z = \cos\delta\cos\phi\ \cos\omega + \sin\delta\sin\phi$$

When the surface is tilted towards the equator (facing south in the northern hemisphere):

$$\cos\theta_i = \cos\delta\cos(\phi-\beta)\cos\omega + \sin\delta\sin(\phi-\beta)$$

All the above mentioned factors were considered for predicting the shadow images of the proposed high rise building. It was predicted on seasonal basis (winter, summer and rainy seasons). Also the prediction was carried out for different interval of day for each season. Site location and its details about the environment were obtained through site survey.

Solar Rating

A particular structure may get cover with shadow from presence of in and around buildings or other structures. This shadow cover could be for whole building or for a particular position of that building in a given time and it could be classified as:

Partial Shadow: A structure receives shadow from other structures at a particular position while other position of the same structure receives sunlight at the same time. This is mainly due to the sun path and structural design. This phenomenon is known as partial shadow.

Full Shadow: When a structure gets totally covered by shadow from other structures and it is total under darkness during daytime. This phenomenon is defined as full shadow.

A particular section of a building could get sunlight at one time of a day; while at its other position could be covered with shadow. The time period for which a section of building receives sun light could be considered as sunlight period for that building. Sunlight period can be further classified as:

Total sunlight phase: The time period for which a particular structure receives sunlight without any obstruction is defined as total sunlight phase or full sunlight phase of that particular structure.

Partial sunlight phase: If a particular structure receives sunlight as well as shadow at same time, this time period is referred as Partial sunlight phase of that particular structure.

Based on the findings and literature, a solar rating was made for the buildings in and around the high rise. This rating was made on the basis of time for which a structure received total sunlight without any obstruction.

Result and Discussions

Shadow is dependent on the position of the building with respect to sun as well as its height [8]. The movement of the sun with respect to ground level for different seasons is given in Figure1.

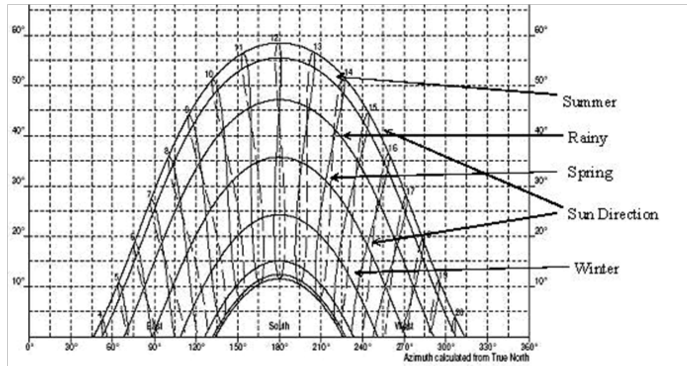

Figure 1: Movement of Sun with respect to Ground Level for Different Seasons.

The length of shadow from the building is dependent on solar azimuth (Figure2), angle of incidence (Figure3), and solar altitude (Figure4) [9,10]. These values were obtained for different seasons for different time intervals of a day. In morning the sun would rise from east and the shadow would be in opposite direction (west) while at evening it would be in the reverse direction. Hence, it was important to obtain the different solar azimuth value for morning and evening.

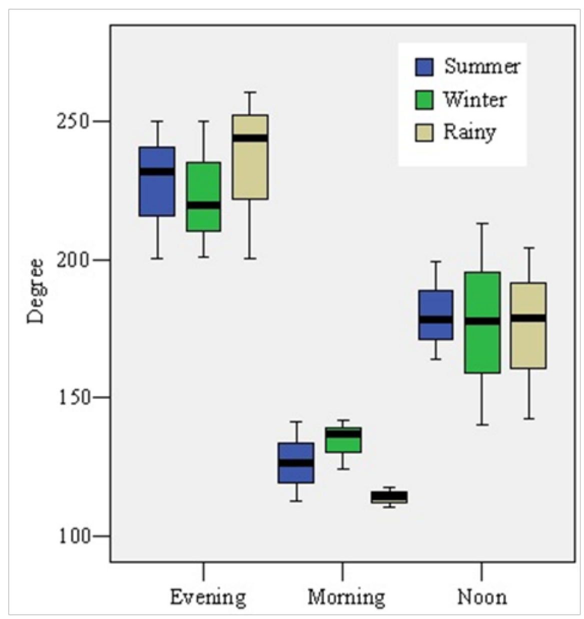

Figure 2: Solar Azimuth Values for the proposed site.

Angle of incidence and solar altitude were almost in similar range for morning and evening time for both summer and winter seasons. But angle of incidence decreased (Figure3) while solar altitude increases (Figure4) in noon time. Kelly and Gibson (2011) also reported similar kind of results in their research.

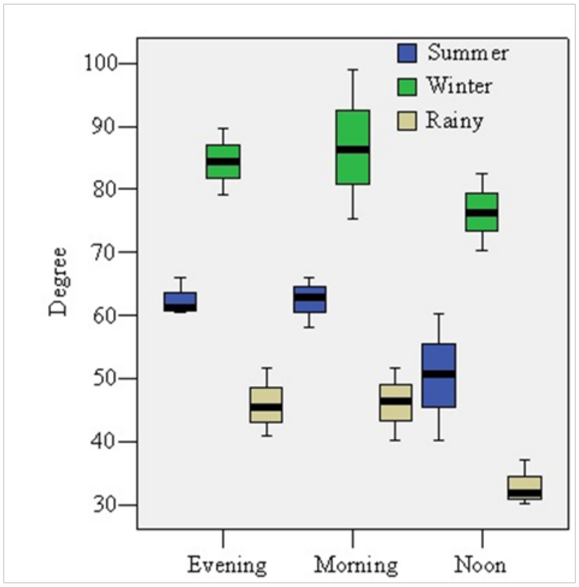

Figure 3: Angle of Incidence for the Study period.

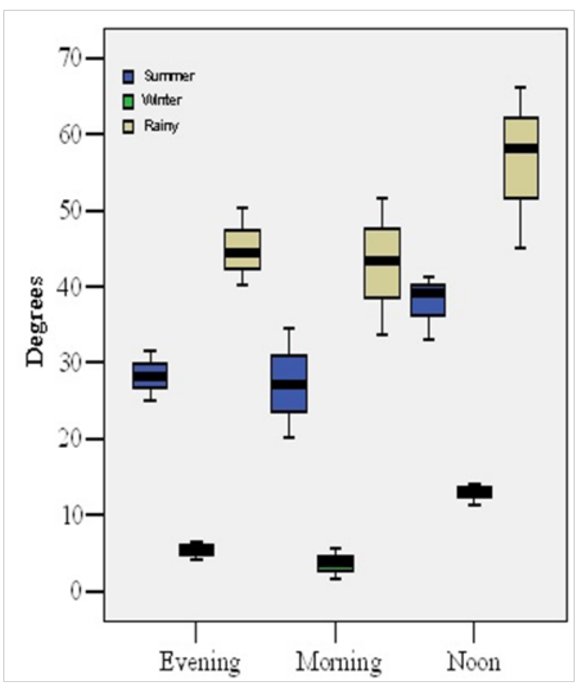

Figure 4: Solar Altitude for the study period.

Location of Proposed High Rise

The proposed high rise was located near One India bulls centre, Lower Parel, Mumbai, India (Figure5). Senapati Bapat marg was at one side of proposed high rise while other side has railway line. The height of the proposed high rise was 301.5 m and it would be a residential unit named "Sky Forest". It would be built by India bulls Infrastructure Pvt. Ltd. Grp of Bld (B) was located at northwest direction with respect to the proposed site, where as Grp of Bld (C) was located at west direction (Figure6). A ground and green cover were also present at this location which was directly opposite to the proposed high rise. There were two Chawls located at north-northwest direction. They were marked as Chawl (C) and (D). Chawl is residential unit and they have height of about 15-20 m. Two arterial roads were present along these Chawls. A construction site was located at the north direction of the proposed high rise (details of it was not available). Two more chawls were present in the north-northeast direction of the proposed high rise. They are marked as Chawl (A) and (B). The Grp of Bld (A) was located at its northeast direction.

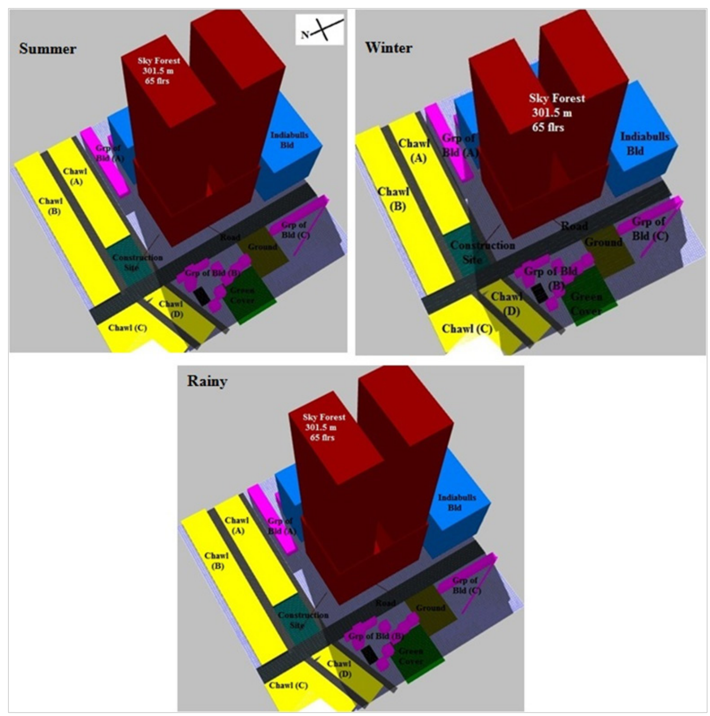

Figure 5: Probable Shadow of different seasons with proposed High rise at morning time.

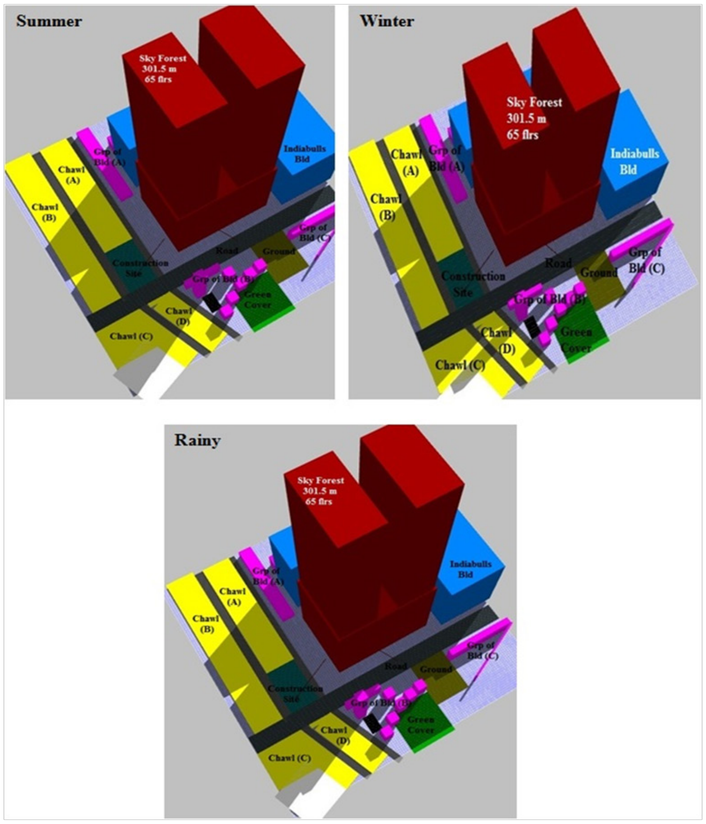

Figure 6: Probable Shadow of different seasons with proposed High rise at Midday.

Comparison of Shadow with Proposed High Rise for Different Seasons

During summer season in morning time, the shadow of the proposed high rise would fall on Grp of Bld (B), Chawl (D), ground and green cover adjacent to it. Grp of Bld (C) would be covered by shadow by commercial building of India bulls (Figure6). But the rest of the structures present in the vicinity of the proposed high rise would get enough sunlight during this period.

As the day progressed the sun changed its path. Due to this, the direction of the shadow changed to north (Doran et al. 2003). During midday of summer season the merged shadow of proposed high rise and two commercial complexes of India bulls would fall on Grp of Bld (A) and (B), adjacent ground, Chawl (A), (B), (C) and (D) (Figure7). But the construction site would get totally covered by this merged shadow.

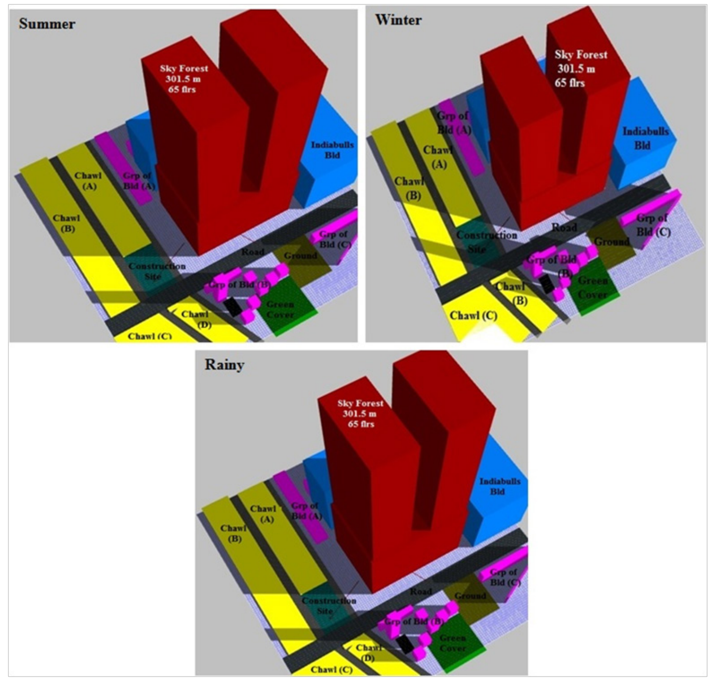

Figure 7: Probable Shadow of different seasons with proposed high rise at late afternoon.

At late afternoon the shadow would shift towards east direction. During this time, the merged shadow from proposed high rise and commercial complexes of India bulls would fall on Grp of Bld (A) and Chawl (A). They would be totally covered with shadow. Chawl (B) and construction site would get partially covered with shadow (Figure8). Similar pattern of shadow was observed for morning time for all the different seasons. Comparing winter season shadow, it was observed that during winter season the merged shadow from the proposed high rise and other building has got shifted towards north-northwest direction

Shadow Cover Without Proposed High Rise

As per the current situation of the proposed location, the probable shadow could be as per the Figure 9. It was observed that there was not much difference in shadow without the proposed high rise during morning and late afternoon time. However, in case of midday, significant difference was observed. After construction of high rise, it would accumulate the shadow from the existing structures of India bulls on the surrounding area. Due to the height of proposed high rise, the shadow could be longer in length as per current situation. This merged shadow would last for longer duration of the day.

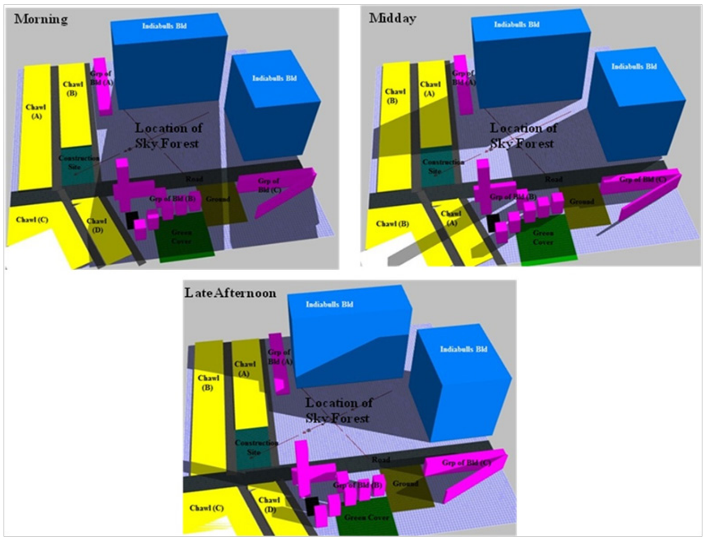

Figure 8: Probable shadow without the proposed high rise.

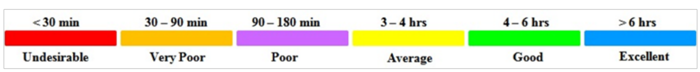

Figure 9: Solar rating criteria

Solar Rating

A particular structure in and around a high rise might get cover with shadow. This shadow would dependent on the duration of day, seasons, design and structure of buildings in and around the high rise. Plants require 4-6 hours of sunlight in a day for photosynthesis [11]. Building requires sunlight [12] for optimal functioning of its solar systems [13], betterment of human health [14], for natural illumination [15], its own maintenance like preventing algal growth on its wall [16], improving indoor air quality [17,18] and for natural heating [19]. Children require sunlight for their growth and development [20]. while elderly people requires sunlight for normal functioning of body [21]. A solar system requires about 4 - 6 hours of sunlight in a day for its optimum functioning [22]. As per European condition minimum 2 hours of direct sunlight is required for a structures around a high rise buildings [23]. Mumbai has hot and humid climate throughout the year. Most of the year, it has clear skies and hence better solar intensity as compared with other western countries [24]. Based on the climatic condition of Mumbai and findings from different literature, a solar rating was developed for neighborhood structures in and around the high rise. This rating was dependent on height and design of the buildings or structure, and other components present in and around that high rise. This rating was based on time period for which a structure received total sunlight. It is given in Figure10. This sunlight rating is important for the decision making bodies like urban Municipality. This would allow sustainable development across developing countries [25]. This kind of rating is needed to be implemented for betterment of environment and society for long term point of view.

It is important that a structure must receive at least 2 hours of uninterrupted sunlight for a day. If a structure received less than 30 minutes of sunlight in a day then that structure was placed in undesirable category of solar rating. This rating consisted of different time interval for which a building or structure around a high rise received sunlight. Applying this rating on the neighborhood structure of proposed high rise, it was observed that most of the neighborhood structure would receive sunlight for 4 – 6 hours (Table1). Thus these structures were in good category as per the solar rating while Chawl B was under average category for solar rating. Construction site and Chawl A would be receiving sunlight for less than three hours a day. Hence they were rated poor as per the category. Chawl D was surrounded by various buildings around it. Also height of Chawl D was less as compared with its surrounding structures. Hence it was receiving shadow for longer duration and thus it was placed in very poor category of solar rating. Ground was also surrounded by many small and tall buildings around it. Due to this, it was receiving interrupted sunlight throughout the day. Hence it was placed in undesirable category of solar rating. Also all these structures were receiving partial sunlight in a given day. This partial sunlight phase of different neighborhood structures is given in Table2. Most of the neighborhood structures were receiving partial sunlight for more than 4 hours a day while some was receiving for 2 – 4 hours (Table2). Only green cover was receiving partial sunlight for less than 2 hours in a day. This was mainly due to height as well as different neighborhood structures around it.

Table 1: Probable sunlight period and respective sunlight rating for different structures

Neighborhood Structures	Sunlight period (All seasons)	Solar Rating
	Full (without any obstruction)	
Chawl A	2 hours 50 minutes	
Chawl B	3 hours 30 minutes	
Chawl C	4 hours 50 minutes	
Chawl D	1 hour	
Construction site	2 hours 30 minutes	
Green Cover	5 hours 20 minutes	
Ground	0 minute	
Grp of Bld A	5 hours 10 minutes	
Grp of Bld B	4 hours 30 minutes	
Grp of Bld C	4 hours 30 minutes	

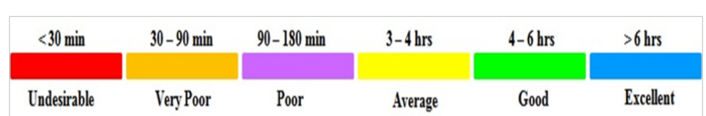

Table 2: Partial sunlight phase for neighborhood structures

Neighborhood structures	Partial sunlight phase
Chawl A	4 hours 50 minutes
Chawl B	7 hours
Chawl C	5 hours
Chawl D	7 hours 10 minutes
Construction site	5 hours 10 minutes
Green Cover	1 hour 30 minutes
Ground	5 hour 40 minutes
Grp of Bld A	2 hours 30 minutes
Grp of Bld B	3 hours 20 minutes
Grp of Bld C	2 hours 30 minutes

Conclusion and Recommendations

The proposed high rise was surrounded by two commercial complexes of India bulls. In morning time, (for all the seasons) merged shadow from proposed high rise and commercial complexes of India bulls would fall on Grp of Bld (C), Grp of Bld (B), ground, green cover and Chawl (D). Similarly at midday (for all the seasons), the shadow from the proposed high rise would fall on Chawl (C) and (D). These structures would also receive shadow from Grp of Bld (B). Construction site would be totally merged under shadow during this phase. During late afternoon (for all seasons), the merged shadow from the proposed high rise and commercial complexes of India bulls would fall on Chawl (A) and (B).

As per the solar rating, Chawl (D) and ground was most critically affected by shadow. This was mainly due to their location and height. Also the surrounding structures around it were responsible for interrupting direct sunlight falling on them. Remaining structures were receiving sufficient sunlight in a day. Also most of these structures were receiving adequate partial sunlight in a day. Thus, from this study the following recommendations were drawn while proposing construction of high rise structures, in terms of shadow affect:

Site planning should take into account the proposed high rise structures as well as different neighborhood structures in and around it. In this study, we found that existing commercial buildings of India bulls were already casting shadow on neighborhood structures. Thus by construction of the proposed high rise, shadow effect was cumulated as per present scenario. Hence site planning is important.

This site planning should also consider the existing structures in and around the critically affected areas or structures

Shadow from high rise is dependent on height, width, breadth and its structural design. Hence all these factors should be considered for neighborhood shadow analysis.

Distance between the proposed high rise and existing structures should be considered for predicting its shadow effect

A high rise should not adversely affect the morning sunlight on any of its neighboring structures

A high rise should be design in such manner that it should not cast its shadow for longer duration on a particular structure

Acknowledgement

This study was funded by India bulls Infrastructure Pvt. Ltd. Authors are thankful to all the support and data sharing by India bulls team.

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