

Effect of Street Morphology on Microclimate in Residential Areas Following FAR Rule in Dhaka City

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ABSTRACT: Microclimate within the streets is affected by its morphological character, geometric pattern, orientation, built density and available green spaces. In residential areas of Dhaka, street morphology is an outcome of the abutting building forms, usually controlled by building construction rule. The Metropolitan Building Construction Rules BCR 2008 recently introduced the application of Floor Area Ratio (FAR). Through implementing this FAR rule, increased building height, relatively smaller building footprint and free ground floor have created an urban street canyon having fragmented canyon walls. This paper presents the results of an investigation how the implementation of FAR impacts comfort criterion for outdoors in reference to microclimates. Spatio-temporal characteristics of the ambient climate such as outdoor air temperature, surface temperature and wind speed conditions in the urban hot and humid environment, at pedestrian level are studied. Results from an intensive field survey including thermal imaging of canyon surfaces were studied at random locations of different street orientation in a planned residential area of Dhaka city. Computer based simulation results as well as recorded field data were analysed, correlated and observed in terms of canyon ratio. Possible guidelines for amendment and adjustment of the FAR rules are discussed in order to enhance urban microclimate in residential areas.

Keywords: Street morphology, urban microclimate, outdoor thermal comfort, FAR rule

INTRODUCTION

In the context of rapid urbanization and dwindling urban open spaces the street remains as the most viable and sustainable feature of urban design ensuring not only means of communication and mobility but also spaces that render natural ventilation and light within the urban fabric. Dhaka, as an urban centre of a developing country, has been rapidly growing without effective planning. Being a tropical city, this kind of unplanned urbanization creates significant impacts on the natural and built environment and affects comfort and human health as it damages the environmental quality of liveable urban spaces. Among the urban spaces, streets affect both outdoor and indoor microclimates and hence influence the thermal comfort and the energy use [1]. Usually, the geometry of a street canyon are expressed by its 'aspect ratio' including the ratio of the height of the building (H) to width of the street (W) [2]. A street canyon refers to the space which is formed by two typically parallel rows of buildings separated by a street [3] where 'aspect ratio' is a significant parameter. Urban geometry has a complex influence on the micro-climate of an urban environment [4]. Independent design features such as fraction of urban land covered by buildings, distances between buildings, including streets' width, average height of buildings affect urban climate in different ways [5]. Urban microclimates are characterized in terms of wind speed and direction, mean radiant temperature, air temperature and relative humidity [6]. As streets cover around a quarter of urban areas, designing streets is a key issue in a global

approach for an environmental urban design. The geometry of streets (H/W) and orientation directly influence the airflow and solar access in urban canyon and therefore thermal comfort at pedestrian level [2]. The impacts of street geometry, i.e. aspect ratio (H/W) and street orientation, on outdoor thermal comfort, both have already been recognized as having considerable influence on the microclimatic changes within urban structures [7, 8, 9,10, 11, 12].

The Metropolitan Building Construction Rules (BCR) 2008 of Dhaka city recently introduced the application of Floor Area Ratio (FAR) where building height was permitted at a compensation of ground coverage and maximum ground coverage is controlled to enhance the environmental, social and aesthetic value of a neighbourhood. The climatic conditions within the canopy, which is limited to the height of buildings in given location, are directly related to the physical characteristics existing in that area, such as geometry and surface materials [13]. Hence, Canyon geometry which can have variations due to FAR rules and orientation of the street canyon, influences the thermal comfort at pedestrian level as well as the energy consumption of urban buildings [14]. Measurement of building geometry includes a) building height/canyon width (H/W) ratio, b) sky view factor, [15], and 3) compactness index, [16, 17]. It was found by Arnfield [10] that the effects of H/W ratio and orientation of streets on receiving solar energy by ground and other street surfaces are more significant in latitudes 20° - 40°

in different seasons. This illustrates that in the subtropics climates, street geometry is more important for the solar control. In fact, height of building is an independent design feature that can affect urban density as well as the urban climate in many ways. Studies in Pune, India showed that the unplanned rising of building height causes the discomfort in the city [18]. Hence, extensive researches are required on urban canyons focusing building H/W ratios in terms of outdoor thermal comfort especially for warm humid regions like Dhaka.

THE CONTEXT OF THE STUDY

This research is based on Dhaka, Bangladesh, a location in the tropical monsoon climate zone. Heat stress in summer is a growing environmental concern for the city; thus it is important to assess the effects of building height on outdoor microclimate in the city [19]. In this study, the microclimate climate is assessed by taking into account air temperature, mean radiant temperature, relative humidity and wind speed. This study is mainly concerned with the climatic aspects within the urban canopy layer. Dhaka city is a fast growing mega city in the world located at 23.24°N, 90.23°E and 8.8 m above sea level. About 13 million people live in the metropolitan area and the density of population is about 23,029 persons per sq. km in the capital city [19]. To accommodate this large population, the city is growing both horizontally and vertically. This study is based on Uttara model town, a planned residential area located at the northern part of the city, which is still expanding through different phases. Up to 2006 the height limitation of building was 6- storied in this area. Height of 1-storied building is about 3m. This study is carried out for hot and dry summer conditions during May. During this season, probabilistic extreme predicted maximum temperatures in April to be as high as 39.1°C (1 in 4 years), 40.2°C (1 in 10 years) and 41.0°C (1 in 25 years) [20].

OBJECTIVE

The main objective of this research is to study the effects of street morphology (different street canyon shapes and orientations) on the microclimate comfort criterion for outdoors in warm humid Dhaka while implementing FAR rule in planned residential areas. This research also aims to identify the provision of amendment and adjustment of the FAR rules to enhance urban microclimate in residential areas in Dhaka.

METHODOLOGY

Relevant published documents as well as researches previously conducted on street morphology, urban canyon, urban microclimate, outdoor thermal comfort

and FAR rules have been extensively studied. Eight planned residential areas within Dhaka city such as Dhanmondi, Uttara, Gulshan, Banani, Baridhara etc were initially observed and ‘Uttara residential area’ (which is still expanding through phases) was selected for reconnaissance survey considering the availability of orthogonal roads (E-W and N-S) in those areas. As there is no such roads in those residential areas having all buildings constructed under FAR rule, the reconnaissance survey was conducted with an aim of short listing at list 20 orthogonal roads (secondary and tertiary) of same widths where at least 50% of the buildings have followed FAR rule of 2008. In that reconnaissance survey, all the orthogonal roads of Uttara residential area were extensively visited.

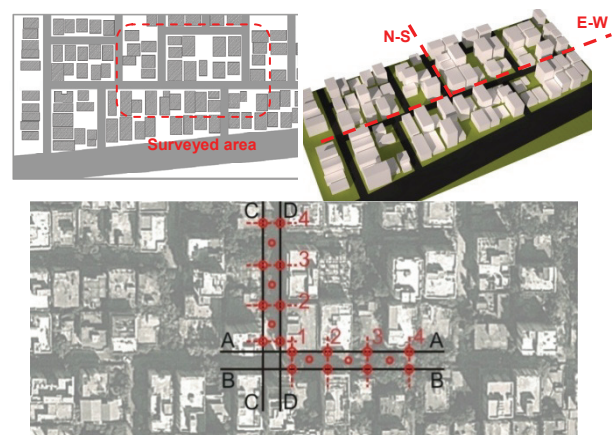


Figure 1: Selected N-S and E-W canyons and surveyed spots

Ten numbers of N-S and ten E-W oriented tertiary roads of 10 meter width and 335 sqm (5 ‘katha’) road-side plots were shortlisted and were photographed. Detail field survey and data collection at 22 spots (figure 1), 1.6 m above ground level, were executed in randomly selected two different oriented roads among these shortlisted streets. It has been found that in case of outdoor situations radiant temperature corresponds better with comfort perception than air temperature [22]. Air temperature, radiant temperature, relative humidity and air velocity data were collected simultaneously with the help of a digital Hygro-Thermometer (Zeal, Model: SH-110) and Vane anemometer (V&A, Model: VA 8020). While collecting data with above instruments, thermal imaging cameras (FLIR i5 infrared camera by FLIR systems) was simultaneously used to capture thermal images. The images were compared with digital photographs; considering same frames to identify the effect of the building, road and pedestrian surfaces temperature. The reconnaissance and field survey was conducted during the month of March-May as it is the hot dry season in Dhaka; hence effects of radiant environment are most pronounced [20].

After analysing the field data, simulation was conducted in total two phases. ENVI-met model which is a widely accepted high-resolution 3D environmental modelling tool to simulate the diurnal microclimatic changes within urban structures [23] has been used in these phases. In phase-1, ENVI-met (version 3.1) simulation modelling was done per to existing profile of the spots (figure 1) along with the surroundings. For simulation study surveyed location, scale, date, time, building height, trees as well as weather data input were taken into consideration for the calculation. Calculations were performed for a 9m x 9m x 9m grid net over the model and the microclimatic data were then extracted for 1,6m above ground level. In phase-2, the surveyed area was considered by projecting all buildings constructed under FAR rules and the simulation was subdivided into two parts in terms of building placement within the plots creating different aspect ratios of the streets. Symmetrical canyon was considered in this case as such ‘canyons’ characterized by their length, building height (H) and street width (W) and orientation’ [24]. According to the building code; 335 sqm plots, can have a maximum of 62.5% ground area coverage considering free open ground floors as an effective parameter, having FAR of 3.5 [25]. These parameter leads to different canyon aspect ratios as an outcome of FAR rule. Comparative analysis between the simulation results of phase-1 and phase-2 was executed in order to achieve both aims of the research. Though building height can be increased through reducing ground coverage, from field survey it was observed that buildings have not exceeded 10 stories in which ground coverage became 40%. Hence for simulation, buildings were placed in two extreme locations within the plots with ground coverage considering 40% and having an FAR value of 3.5. This facilitated analysis of the impact of different aspect ratios.

ANALYSIS OF FIELD SURVEY

Analysing the meteorological data and the recorded field data, it was observed that the average recorded DBT is about 3.15°K higher than meteorological data, while average RH and Wind speed is about 12% and 1.5 m/s lower than the meteorological data respectively (Table 1).

Table 1: Comparison among met. data and field data

	Met. Data	E-W	N-S	Difference between canyons	Avg. Recorded data	Difference with Met. Data
Avg. DBT (°C)	33	36.6	35.7	0.9	36.15	3.15
Avg. RT (°C)	-	35.4	34.6	0.8	35	-
Avg. RH (%)	69	55.5	58.5	-3	57	12
Avg. Wind Speed (m/s)	2.2	0.7	0.7	0	0.7	1.5

Moreover, the recorded field data from the selected spots (figure 1) reveal that, DBT and RT in E-W street canyons are notably higher (average 0.9°K and 0.8°K respectively, Table 1) than that of N-S street canyon. On the other hand, RH in E-W street canyon is relatively lower than that in N-S Canyon.

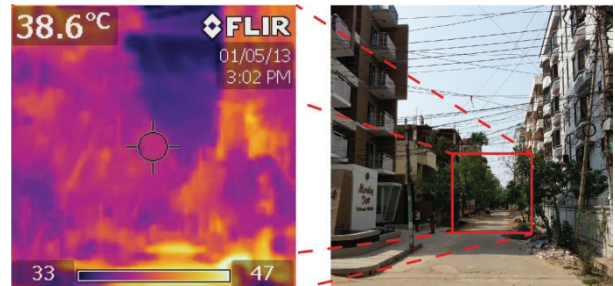


Figure 2-a: Temperature profiles by thermal imaging (N-S)

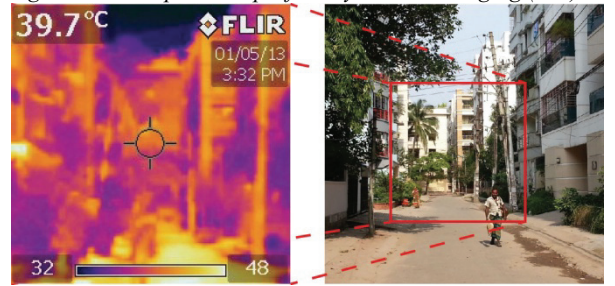


Figure 2-b: Temperature profiles by thermal imaging (E-W)

From the thermal images and digital photographs (figure 2-a, 2-b), it is quite clear that N-S street canyons having less thermal impact (less solar radiation on the surfaces) than E-W roads during the surveyed time due to sun exposure on building facades. In terms of N-S roads the shadow of buildings reduces the thermal impact on the streets. It also indicates that the radiant temperatures (RT) as a result of direct solar radiation and hot surfaces (i.e. street surface, building facades) contribute to increase the temperature and simultaneously controls the Relative humidity and wind velocity of both canyons in pedestrian level.

Table 2: Correlation coefficients among recorded field data

Correlation Coefficients	NS - DBT (°C)	NS - MRT (°C)	NS - RH (%)	NS - Wind (m/s)	EW - DBT (°C)	EW - RT (°C)	EW - RH (%)	EW - Wind (m/s)
NS DBT (°C)	1.0							
NS-RT (°C)	0.6	1.0						
NS-MRH (%)	-0.8	-0.5	1.0					
NS - Wind (m/s)	0.5	-0.2	-0.7	1.0				
EW-DBT	-0.6	0.2	0.5	-0.8	1.0			
EW - RT (°C)	-0.9	-0.2	0.7	-0.7	0.9	1.0		
EW -RH (%)	0.6	-0.2	-0.4	0.8	-1.0	-0.9	1.0	
EW- Wind (m/s)	0.4	-0.4	-0.2	0.7	-1.0	-0.8	1.0	1.0

‘Correlation’ analysis with all available field evidence was also done by Microsoft Excel Data Analysis. Correlation coefficients (table 2) which are within the range of “-0.5 ~ -1.0” and “0.5 ~ 1.0” illustrates that there are significance positive and negative correlations among the DBT, RT, RH and wind speed. Among them

the stronger significant correlations can be observed in E-W street canyon (coefficients are close to +/- 1.0).

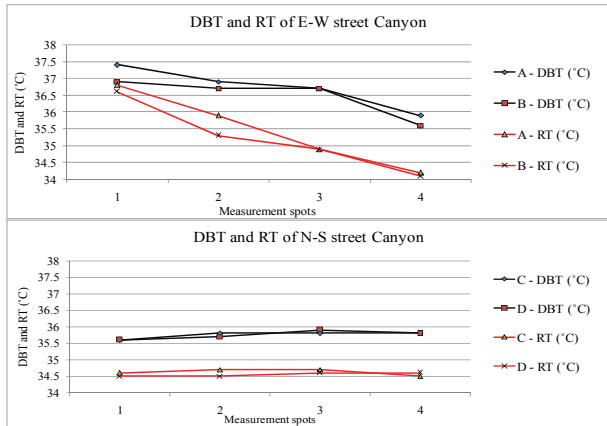


Figure 3: Recorded DBT and RT of street canyons

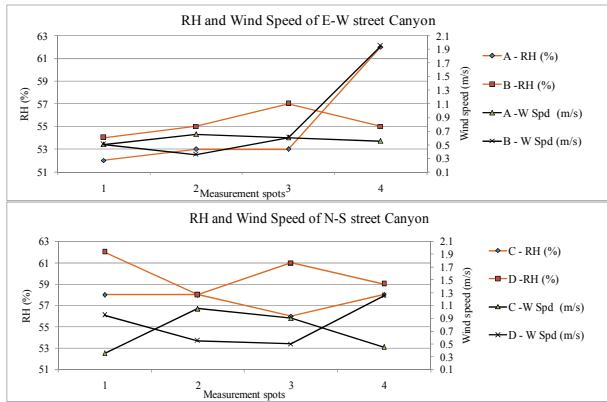


Figure 4: Recorded RH and Wind Speed of street canyons

‘Figure 3 and 4’ reveal that DBT and RT in N-S street canyon do not vary enough in various surveyed spots of the area. In contrast, the DBT and RT drop approx. 2°C from spot-1 to spot-4 (figure 1). It also indicates that due to the shades of the building in N-S canyon, the DBT and RT is a bit lower and does not have enough variations. However, in E-W canyons, the direct solar radiation and solar gain by the hard surfaces increase the DBT and RT at the canyon. The vegetations near the spot 3 and spot 4 also provide shade and contribute to reduce the DBT and RT and to increase the RH. Moreover, wind pattern in E-W streets canyons varies as well which has impacts on the microclimate of that canyon. According to the literature survey, several studies indicate that the pattern of an existing regional wind is changed when it flows through a built environment [25]. Hence, designing built environment and especially street canyon is a key factor in formation of urban wind patterns [2]. In the field survey, the average wind flow is lower in the E-W canyon which also supports the above statements of Shisheger [2]. Thus the Canyon ratio of E-W Street which can be manipulated by the FAR rule may has effects on wind pattern and above all the microclimate.

SIMULATION STUDY AND RESULTS

Strong correlation between canyon ratios and orientations and the level of human comfort within the canyons were established with the use of ENVI-met simulation [14]. In this part of the research, simulation study has been conducted in two phases as discussed earlier to analyse the above issue in context of Dhaka’s planned residential area where variation of canyon shapes is a result of implementing FAR rule. Three cases were compared in the simulation study. Case 1, 2 and 3

Case 1: Existing situation (figure 1) under developing phase i.e. not all plots are developed.

Case 2: Modelled by placing the buildings to generate canyons with low H/W ratio (figure 5a) assuming the development under FAR Rule.

Case 3: Modelled by placing the buildings to generate canyons with high H/W ratio (figure 5b), assuming the buildings construction under FAR Rule.

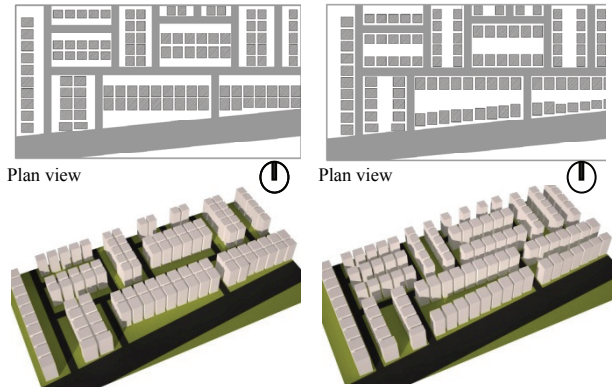
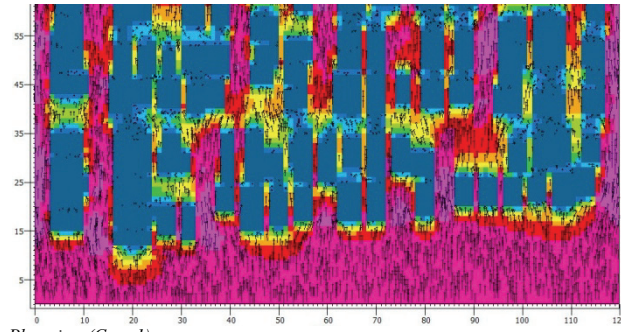


Figure 5a: wide canyons (case 1)

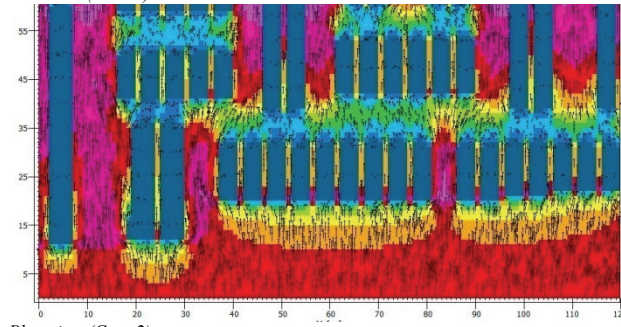
Figure 5b: deep canyons (case 2)

By comparing all the results from simulation studies, two significant correlations have been observed in E-W canyon. H/W ratio has significant impact on the wind flow in E-W canyon (Correlation coefficient -0.66) which reflects an inverse relationship. To increase the wind speed of E-W canyon at pedestrian level low H/W ratio of the canyon is preferable. However, Canyon H/W ratio has no significant impact in wind speed at N-S Street due to the same direction from south towards North. Continuous N-S Street shows better result than discontinuous canyon in terms of wind speed in all three cases (figure 6).

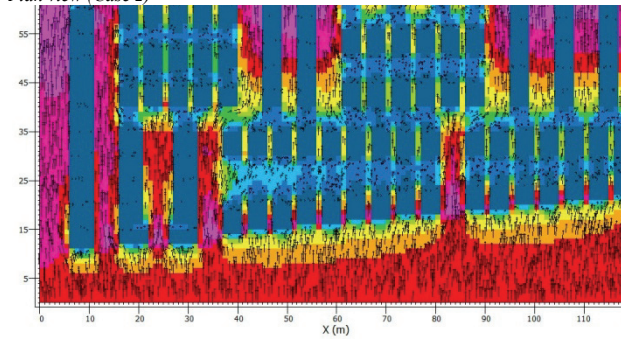
MRT in the E-W canyon shows a strong positive correlation with the canyon ratio (correlation coefficient 0.97). As the built form does not play major role in shading E-W canyon, low H/W ratio in E-W canyon decreases the MRT through increasing soil area (setback area) and reducing radiant hard surface ratio.



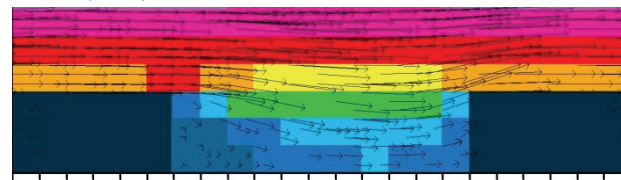
Plan view (Case 1)



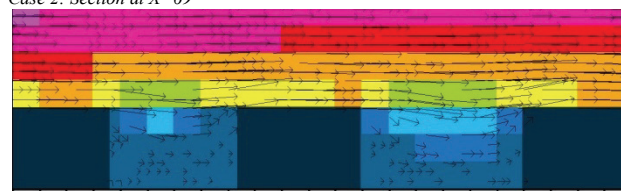
Plan view (Case 2)



Plan view (Case 3)



Case 2: Section at X=69



Case 3: Section at X=69

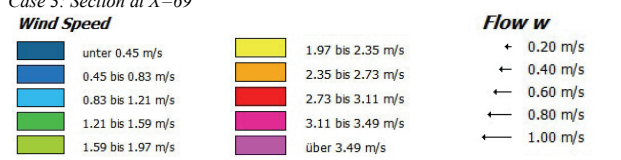


Figure 6: Air flow simulations in three cases

From field survey it was observed that tree-plantation provides shades at pedestrian level and reduce MRT

considerably (Figure 3). Therefore, Shading can be achieved through plantation in E-W canyons. In simulation study, MRT in the N-S road was always lower than the E-W road in all the cases. It illustrates that built form has a significant role in providing shade in N-S canyons only. By detail analysis of the sun angle this impact can be interpreted statistically in terms of minimum H/W ratio for N-S Canyon.

CONCLUDING REMARKS

This paper presented a discussion on the findings on urban microclimatic conditions in reference to building codes and planning regulations based on field based and parametric investigation. Two design experiment sequence were subjected to numerical simulations and analyzed individually to derive the performance of street canyons of different H/W ratio.

The main findings from the analysis are:

- From the field survey it was revealed that overall N-S canyons are cooler than the E-W canyons and in our case the difference was around 0.9 °K.
- Higher H/W ratio (deep street canyon) may be preferable for N-S streets due to the potential shading effect of the built form in reducing MRT.
- Lower H/W ratio (shallow street canyon) may be preferable for E-W streets for better wind ventilation at pedestrian level and low MRT due to the impact of setback and by providing a scope tree-plantation.
- Proper plantation and vegetation is only preferable for E-W street canyons to create shading and reduce MRT. Whereas for the deep canyon in N-S streets, that is already shaded by built form, vegetation will only create obstruction to the wind flow.
- N-S canyons should be continuous without any staggering for better wind flow at pedestrian level.

The current building regulation other than indicating setbacks does not provide guidance for placement of the building on a plot nor about building height. However 'Form Based Coding' [28] should be incorporated in the Metropolitan Building Construction Rules (BCR) 2008 in conjunction with FAR rules to ensure a comfortable microclimate.

Possible amendments in the current building regulation can be proposed as follows:

- Front setback for the plots adjacent to the E-W streets should be increased to create wide canyon along the E-W direction and front setback for plots adjacent to the N-S streets should be minimised to ensure the creation of deep canyon along the N-S direction.
- Mandatory open space including 25% 'soakable' (mandatory unpaved portion) ground should be placed adjacent to the street for plots along the E-W road for creating canyon of low H/W ratio. In contrast, open

space should be placed at the rear side of the building in plots adjacent to the N-S road.

- N-S street canyon with 2:1 H/W ratio usually provides maximum shading at pedestrian level, corroborates the finding of Ahmed [27]. Hence, for 6m wide road and 1.5m front setback (General rule for residential area in Dhaka) the minimum building height should be 18m or 6 storeys along the N-S street canyons to ensure maximum shading.

The problem investigated here also has other dimensions and demands further detail research and larger experimental study. For example elevated block were not tested here as this morphology generates the soft-storey situation and is discouraged due to increased earthquake vulnerability. Different building geometries and other seasonal variations should also be taken into account in further research.

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