

Impacts of ‘Maximum Allowable Building Footprint’ on Natural Ventilation in Apartment Building

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ABSTRACT: This study investigates the relationship between indoor natural ventilation and a key building regulation component - Maximum Allowable Building Footprint (MABF). Determining the amount of open space around an apartment building, MABF significantly affects natural ventilation rates (Air Change per Hour) in individual dwelling units. A case of a 30-dwelling units apartment building, in the dense urban context of Dhaka city, Bangladesh, is analyzed in this study. Impacts of four MABF (50%, 60%, 70% and 80%) are examined. Four different building-forms, each providing thirty dwelling units, suitable for the four mentioned MABF, are considered. A visual survey of Dhaka’s existing apartments is used to identify the studied building-forms. FLUENT, a Computational Fluid Dynamics tool, and ENERGYPLUS, an Energy Simulation tool are used to examine the natural ventilation in the dwelling units. In two studies conducted earlier by this author, where the stated cases were examined, only 30% dwelling units (units on bottom and top floors) were examined. With a more advance computation resource, this study verifies results obtained in the earlier studies, by examining dwelling units of all floors (100% dwelling units). Results from these studies suggest that maximum natural ventilation can be achieved even under higher value of Maximum Allowable Building Footprint (70%, compared to 50%). Complimenting the earlier studies, the findings of this study challenge the prevailing myth about the linear relationship between natural ventilation and amount of open space.

Keywords: Natural Ventilation, Building Regulations, Maximum Allowable Building Footprint (MABF), CFD, EnergyPlus.

INTRODUCTION

Adequate ventilation rates are crucial to flush-out unwanted heat in non-conditioned apartment buildings. However, inadequate ventilation rates are common in such buildings in dense urban areas. Building-foot-prints cover most of the lot area in dense urban areas for economic reasons. This results in lack of open space which consequently diminishes scope of natural ventilation. Maximum Allowable Building Footprint (MABF), a building regulation component, plays significant role in preserving adequate open space. However, preserving open space at the expense of density (unit = Dwelling Units/Acre) is not pragmatic since it results in agricultural land encroachment in the city outskirts. Therefore, investigation on the relationship between natural ventilation, varying MABFs, and a constant density is important.

Existing literatures do not clearly define the relationship. Most relevant studies analyzed the relationship between density and outdoor ventilation. Among these, only in a few studies, density was considered as a constant; others conducted ventilation analysis under varying density. Fahmy and Sharples [2] analyzed ventilation potential under three types of density –i) high density – narrow gaps between five-story buildings, ii) medium density - little wider gaps between four-story buildings, and iii) low density - wide gaps between one or two story villas. The study shows that higher ventilation potential exists in low density

context. Grosso and Banchio [3] studied the impact of plan area density on wind driven cross ventilation in urban areas. Their study considered five European locations with varying plan area densities, and showed that a decrease in plan area density increases wind driven cross ventilation. Su [12] studied outdoor ventilation for two different building configurations with a similar Floor Area Ratio (FAR). One is a single story, and the other is double story but its plan area is half of the former. The later configuration shows a 18-20% improvement in outdoor ventilation.

The above studies show that lower plan area density with constant building volume provides better ventilation; but interpreting this idea in terms of MABF was not their study objective. Moreover, magnitude of ventilation improvement, in terms of indoor ventilation rates (Air Change per Hour), was also beyond their study objective. To address this gap in the literature, this study examines indoor ventilation rates in four different simulated apartment buildings, each addressing a unique value of MABF (unit = percentage) but a common value of density (unit = DU/Acre). The four values of MABF are 80%, 70%, 60%, and 50%; the value of density is 90 DU/Acre. The lot size considered in this study is 1/3rd acre. Therefore, each of the simulated buildings house thirty dwelling units. Table 1 shows brief information about the four simulated buildings.

Table 1: Details about four simulated apartment buildings

Compliance with Building Regulation	MABF	Units / floor	Building height
1996	80%	6	6-stories (1 st floor–parking)
Hypothetical-1	70%	5	7-stories (1 st floor–parking)
Hypothetical-2	60%	4	9-stories (1 st and half of 2 nd floor–parking)
2008	50%	3	11-stories (1 st floor–parking)

The work presented in this paper is an extension of two earlier studies [6, 7]. Since the context of the investigation is the same, this paper is not repeating the background behind choosing the values, reported in Table 1. In the earlier works, only 30% dwelling units (units on bottom and top floors) were examined, due to limitation in computation time. Using a longer time frame, this study examined dwelling units of all floors (100% dwelling units).

METHODOLOGY

Since this is an extension of earlier studies, and the same methodology was followed, this section has been copied and modified after the earlier publications [6, 7].

Selection of building-forms to match the values of selected MABFs

To analyze the impact of an MABF on indoor ventilation rate, an appropriate building-form has to be selected. A building-form that complies with 80% MABF and that allows six units per floor (Table 1), will not comply with 50% MABF and it will not allow six similar size units on each floor. However, there are more than one possible building-form for each value of MABF. Examining all possible building-forms is beyond the scope of this study. Therefore, one representative building-form for each value of MABF has to be identified. For this purpose, the earlier study performed a survey on existing building-forms; to identify one typical building-form suitable for each value of MABF.

The study found Dhanmondi Residential Area to be the most appropriate location to perform the survey; because its typical lot size is 1/3rd acre. It also offers a number of variations in apartment building-forms. A

visual survey was conducted to identify Dhanmondi's building-form typology. A total of 117 apartment buildings were visually surveyed, to identify and graphically record these apartment buildings' building-forms. The recorded building-forms and their typology were cross-checked by a CAD drawing that documented building roof-prints observed in Dhanmondi's satellite image. The building-form typology as well as number and percentage of each building-form type are shown in Table-2.

Table 2: Building-form typology observed in Dhanmondi residential area

Type number	Satellite image of the building-form	Footprint of the building-form	Number of each type	Percentage of each type	Maximum Allowable Building Footprint (MABF)
1			60	52%	80%
2			21	18%	80%
3			14	11%	80%
4			9	08%	80%
5			5	04%	80%
6			2	02%	70%
7			5	04%	60%
8			1	0.8%	60%

Based on the survey, Type1 was selected for 80% MABF, because it is the most common among the ones that occupy 80% lot area. Type 6 was selected for 70%

MABF since there was no other alternative. Type 7 was selected for 60% MABF because the other alternative (Type 8) was not as commonly used as this one. There was not a single multi-storey apartment building in the studied area that complies with 50% MABF. Therefore, a hypothetical apartment building was designed that fulfilled the requirements. Using the author's professional experience in Dhaka's apartment design industry, a building-form that occupies 50% lot area was generated. Table 3 shows all four building-forms (for four values of MABFs) along with their footprints. The four footprints shown in Table 3 also depict the location of individual dwelling units (A,B,C,D,E, & F).

Table 3: Building-forms and footprints selected for four values of Maximum Allowable Building Footprint (MABF)

Maximum Allowable Building Footprint (MABF)	Building-form	Building footprint with dwelling units' locations
80%		
70%		
60%		
50%		

Selection of simulation tools to calculate ventilation rates

The most commonly used techniques to study wind flow in and around buildings are – i) experimental correlation, ii) inverted salt gradients, iii) wind tunnel testing, iv) airflow network model, and v) Computational Fluid Dynamics [11]. Experimental correlations are simple to use. However, they lack

flexibility to handle variable room geometries, because the correlations are obtained from a particular type of geometry [4]. Both the ‘inverted salt gradients’ and ‘wind tunnel test’ posses the following limitations: i) measurement data of wind velocity are limited to a few points, and ii) instrumentation used for the velocity measurement can disturb flow pattern [8]. Therefore, only ‘airflow network model’ and Computational Fluid Dynamics (CFD) were used in this study to calculate wind data.

In this study, ENERGYPLUS was used to perform the tasks of ‘airflow network model’, and FLUENT was used to perform the tasks of CFD. According to Lixing Gu, “EnergyPlus’ airflow network model was validated against measured data from both the Oak Ridge National Laboratory (ORNL) and the Florida Solar Energy Center (FSEC)” [5]. For validation of FLUENT against measured data, numerous studies have been performed and success was shown [1, 10].

To calculate ventilation rates in individual dwelling units, two sets of simulations were performed for every building. One was an outdoor wind flow simulation using FLUENT, and the other one was indoor wind flow simulation using ENERGYPLUS. The output from outdoor wind flow simulation was ‘wind pressure coefficient’ calculated on exterior windows in the studied apartment building. These ‘wind pressure coefficients’ were then used in ENERGYPLUS as inputs, to calculate ventilation rates in individual dwelling units. Both outdoor and indoor wind simulation procedures are discussed in the previous paper [7].

RESULTS AND DISCUSSIONS

To get complete information about ventilation potential of each value of MABF, all thirty dwelling units in each apartment building need to be simulated. It requires altogether 120 simulations. Moreover, to get an average ventilation rate in each individual dwelling unit, ventilation in all of the rooms need to be simulated too. This requires a long span of time. To make it manageable, the first study [7] only simulated and compared dwelling units on the least privileged locations – units on bottom floors since wind gets weaker near the ground. That study found 70% MABF to be the best option. To examine the validity of that result, the second study [6] simulated and compared dwelling units on the best privileged locations – units on topmost floors since wind gets stronger at higher elevation. The result complimented the earlier findings. However, the author realizes the importance of simulating all dwelling units to get a complete understanding about the ventilation potential of all four values of MABFs. Therefore, this study simulated all the remaining units, and compared with the earlier findings.

Table 4 to Table 7 shows average hourly ventilation rates in all thirty dwelling units in each of the four apartment buildings, representing the impact of all four MABFs. On each of the tables, the columns represent type of dwelling units and the rows represent the floor levels.

Table 4: Average hourly ventilation rates in all thirty dwelling units in the apartment building under 50% MABF

Ventilation rates (ACH) under 50% MABF			
Floors	Dwelling units at different floors		
	Unit-A	Unit-B	Unit-C
2 nd	25	20	20
3 rd	12	23	23
4 th	12	25	25
5 th	12	27	27
6 th	12	29	29
7 th	32	30	30
8 th	47	32	32
9 th	47	33	33
10 th	47	34	34
11 th	42	35	35

Table 5: Average hourly ventilation rates in all thirty dwelling units in the apartment building under 60% MABF

Ventilation rates (ACH) under 60% MABF				
Floors	Dwelling units at different floors			
	Unit-A	Unit-B	Unit-C	Unit-D
2 nd	34	30		
3 rd	40	23	23	30
4 th	29	23	23	23
5 th	31	30	23	12
6 th	30	20	31	12
7 th	23	31	20	20
8 th	23	23	20	20
9 th	23	23	20	20

Table 6: Average hourly ventilation rates in all thirty dwelling units in the apartment building under 70% MABF

Floors	Ventilation rates (ACH) under 70% MABF				
	Dwelling units at different floors				
Unit-A	Unit-B	Unit-C	Unit-D	Unit-E	
2 nd	34	34	28	27	44
3 rd	27	27	32	27	34
4 th	27	43	34	27	43
5 th	34	48	37	27	43
6 th	49	54	39	34	43
7 th	61	62	40	43	58

Table 7: Average hourly ventilation rates in all thirty dwelling units in the apartment building under 80% MABF

Floors	Ventilation rates (ACH) under 80% MABF					
	Dwelling units at different floors					
Unit-A	Unit-B	Unit-C	Unit-D	Unit-E	Unit-F	
2 nd	38	35	11	12	12	12
3 rd	32	28	10	12	12	12
4 th	25	22	10	12	12	12
5 th	25	22	10	12	12	12
6 th	25	22	11	13	13	13

The data tabulated in these four tables show that a 70% MABF has the most potential of natural ventilation. On average, dwelling units under 70% MABF experience hourly indoor ventilation rate of 39 ACH. Dwelling units under 80% MABF experience hourly indoor ventilation rate of 20 ACH. The rate is 25 ACH for 60% MABF, and it is 29 ACH for 50% MABF.

The range of average indoor ventilation rate under the four studied MABFs is between 20 ACH to 39 ACH. Ventilation rate of the upper range is most evident in dwelling units under '70% MABF'. Almost seventy three percent dwelling units get a ventilation rate of 30 ACH or more. This upper values of ventilation rate is not at all evident in dwelling units under '80% MABF'. It is evident in fifty percent dwelling units under '50%

MABF', and is evident in thirty six percent dwelling units under '50% MABF'. On the other hand, the lower range is most common among the dwelling units under '80% MABF'. Almost sixty seven percent dwelling units get a ventilation rate of 20ACH or less. None of the dwelling units under '70% MABF' experience this lower rate. This lower rate is evident in twenty six percent dwelling units under '60% MABF', and in twenty percent dwelling units under '50% MABF'. This comparative analysis is clearly depicted in Fig. 1.

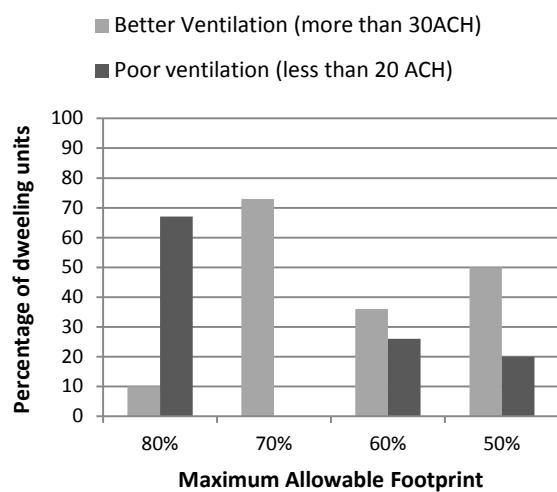


Figure 1: Percentage of dwelling units getting better and poor ventilation rates under different values of MABF

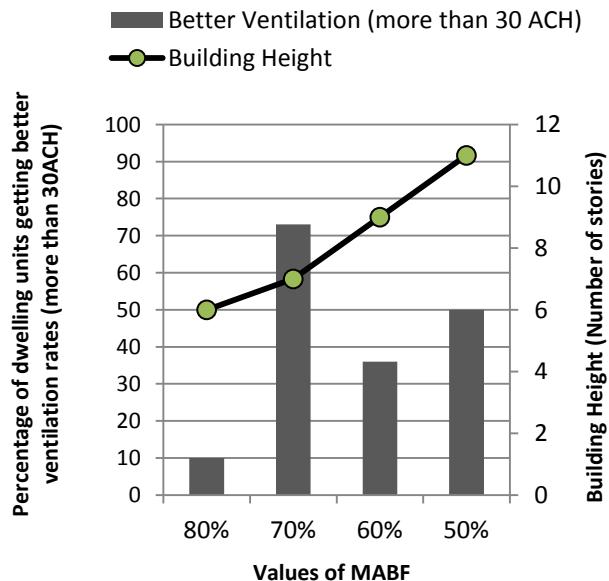


Figure 2: Relationship between Ventilation Rate, MABF, and Building Height

It was expected that higher ventilation rates would be common under lower value of MABF. It was also expected that higher ventilation rates would be most common in the tallest building. However, Fig. 2 shows that higher ventilation rates can be common under higher value of MABF (70% MABF vs. 50% and 60% MABF) if the value is not too high (80% MABF). Fig. 2 also shows that higher ventilation rates can be common in less taller building (7-story vs. 9 or 11-stories). Therefore, it can be said that, in dense urban context, ventilation rates do not increase linearly with the decrease in MABF or with the increase of building height. To critically analyze and understand these study findings, the pressure coefficient contour on building facades, along with outdoor wind flow pattern in all four apartment buildings were examined. Since it is similar to the one that was done in the earlier work [6], the summary of that examination result is copied from the earlier paper and presented in the following paragraph.

Indoor ventilation occurs due to pressure difference in exterior facades. A building in open space experiences high pressure in windward direction and low pressure in leeward direction [9]. This allows wind to flow through the interior naturally. In such buildings, higher wind pressure difference is also observed in top floors since wind speed increases (in open area) along with the building height. However, the analysis done in these three studies suggest that, in dense urban context, wind speed and consequent wind pressure on building facade does not necessarily increase with the decrease of MABF and with the increase in building height. Rather they also depend on building configuration. The U-shaped building-form under 70% MABF experienced stronger turbulence; the Pavilion-shaped building-form under 60% MABF experienced weaker turbulence. There might be a correlation between the turbulence and the consequent pressure difference on the studied buildings. This is beyond the scope of this study, and will be addressed in future. However, it can be said that, in dense urban context, indoor ventilation rates do not increase linearly with the decrease of MABF and increase of building height.

CONCLUSION

The objective of this study is to identify an optimum value of Maximum Allowable Building Footprint (MABF) for Dhaka's overcrowded residential area, which will provide better ventilation in apartment buildings without compromising the existing density. Four simulated apartment buildings, each having a unique value of MABF but a common value of density, is the context of the study. Indoor ventilation rates were examined in these buildings using FLUENT and EnergyPlus. In earlier two studies, only dwelling units on bottom and top floors were simulated due to lack of

computation time. This study simulated all remaining dwelling units. Complimenting the results of earlier two works, this study shows that a value of 70% MABF provides higher ventilation rates (above 30 ACH) in maximum number of dwelling units.

The data gathered in this study also validate three earlier findings conducted by this author. The findings are:

1) ‘Improvement in ventilation rate’ is not proportional to the ‘reduction of maximum allowable building footprint’. Average ventilation rates increased from 20ACH to 39 ACH as MABF values decreased from 80% to 70%. However, it did not increase at the same ratio as MABF decreased from 70% to 60%. Rather it decreased from 39ACH to 25 ACH.

2) Increase in open space alone cannot assure higher ventilation rate in apartment buildings. Rather it is the building configuration that along with adequate open space can contribute in higher ventilation rate.

3) In dense urban context, ventilation rates do not proportionately increase along with the increase in building height. The 7-story building analyzed in this research provides better ventilation rates than the 11-story building.

The findings of this study challenge the prevailing myth about the linear relationship between natural ventilation and amount of open space. Therefore, this study concludes that adequate natural ventilation is achievable even in dense urban areas if building-regulations are carefully devised, and building configurations are carefully arranged.

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