Height Zoning and Street Orientation Perception: Alternative Mechanisms to Minimize the Urban Pollutant Concentration in Dhaka City

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Introduction

It is necessary to enhance urban environmental quality, incorporating the pollutant concentration issues in urban planning as well as in urban design. Day by day the population pressure is increasing in the urban area due to the urbanization phenomenon all over the world. Population pressure influences some other phenomena simultaneously. With population pressure, the travel demand increases that results the heavy traffic volume in the urban area. Due to increasing motorized vehicles, the vehicular emission is increasing as well. In Dhaka city, the air pollution level is increasing in the rate of 7.7% every year. The standard pollution level is left behind many days ago. In Dhaka city, nearly 40% pollution is added due to transport emission alone.

In this study, the estimation and evaluation of CO concentration has been done using air pollution dispersion model (Operational Street Pollution Model). The increase of vehicles is not only responsible for pollutant concentration. Urban density, planning features such as building height, street orientation, and wind flow direction are also responsible for pollutant concentration. In this study, the extent of effect of planning features and wind flow direction on CO concentration have also been considered.

The major portion of air pollution is done by the transport system in every country. In Bangladesh, the motorized traffic volume is increasing day by day with the increase of urbanization. Different organizations in Bangladesh have conducted researches on vehicular emission. Several studies are done for Dhaka City by using different receptor models (Bilkis *et al*., 2005, Bilkis *et al*., 2004, Biswas *et al*., 2001, Khaliquzzaman, 2005, Khaliquzzaman, 2003, Khaliquzzaman *et al*., 2003). Some studies on chemical characterization of pollutants have also been done in the city (Biswas, 1998, Khaliquzzaman *et al*., 1999, Mahbubul, 2005). Traffic pollution inventories at 82 street intersections were estimated using the Gaussian Plume Model (Masud, 1999). But no study has been done to predict the ambient concentration of pollutants for Dhaka city by using any air quality dispersion model. In this respect, probably this study is the first attempt to model the output with the observed data using OSPM. The outcome of this modeling may provide some valuable information about the contribution of different sources in the ambient CO concentration in Dhaka that could help to make effective control strategy.

Day by day, the number of vehicles is increasing due to the high rate of urbanization in Dhaka city. High rate of vehicular increase contributes to high rate of pollution concentration. There is a significant contribution of urban features such as building height and density along the road on the pollutant concentration. No study has been conducted in Bangladesh analyzing the effect of the urban features on the local level pollutant concentration. This study is aimed to find out the effect of planning features on the pollutant concentration in the road space. The objectives are to estimate and evaluate the hourly average CO concentration for Dhaka city using the OSPM (Operational Street Pollution Model) through grid-based CO emission considering one major emission source (vehicular emission); and to assess the effect of planning features on Pollutant (CO) concentration.

Environment is seriously considered while plan is being made. Effects of planning features such as building height and road orientation on pollutant concentration are taken into consideration. This study showed the effect of planning features and wind flow direction on CO concentration. Only controlling the number of vehicles, it is not possible to provide the urban citizen air quality in the road space. For this, there will be need of planning controls. It is not easy to control the traffic, but control of road side development is relatively easier. Controlling the road side development and road orientation, CO concentration can be reduced up to forty percent.

Methodology

In this study, the estimation and evaluation of CO concentration has been done using air pollution dispersion model (Operational Street Pollution Model). The methodology is divided into two parts. First part of the methodology is to estimate and evaluate the CO concentration for a selected road of Dhaka City, and the second part of the methodology is to find out the effect of planning features on CO concentration. Two factors are mainly considered to find out the effect of the road canyon. First one is building height and density along the road and second one is street orientation considering the wind flow direction. For two segments of the study, two study areas were considered. For evaluating the model, the study area was Manik Mia Avenue and for studying the effect of planning features, the road segment of Bata More to Science Lab was taken into account. The study methodology expressed through a framework in Figure 1.

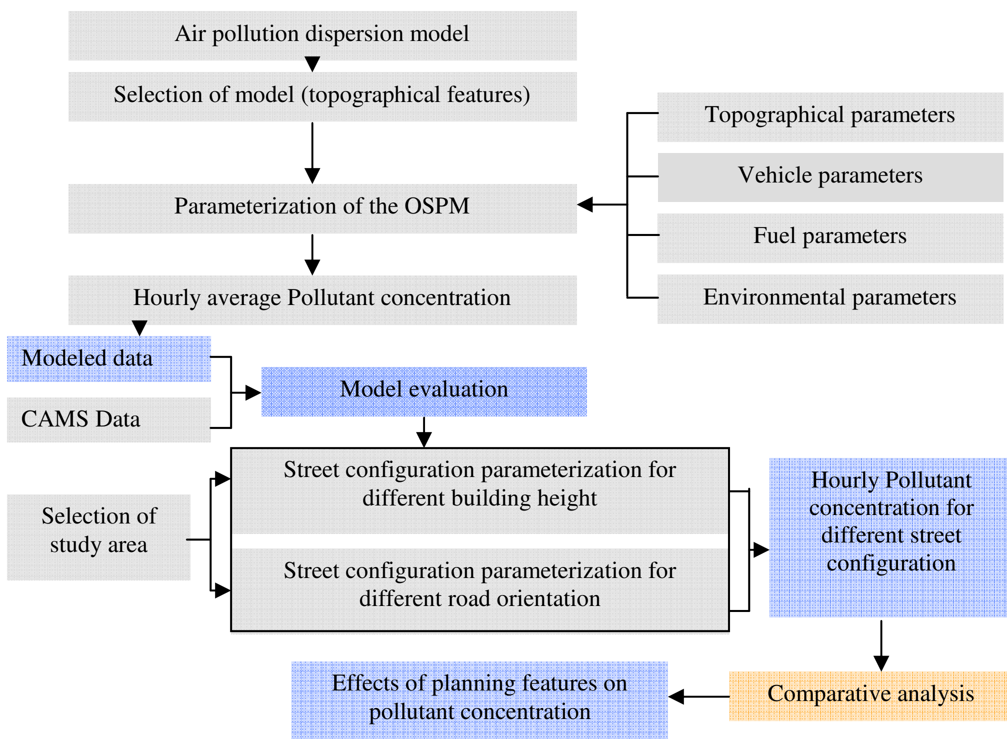


Fig. 1: Flow chart of study methodology

In beginning, Dhaka city was divided into some grids as per the study purpose. Grid cells were made for Dhaka city to get the output from the model. The geographical co-ordinate of Dhaka city is90°l9`E to 90°27`E longitude and 23°41`N to 23°54`N latitude (Muntaseer, 2006). In the east west (X-direction), the city is 8’ wide whereas 13’ in north south (Y-direction). 1’ longitude is equal to 1.590 kilometer and 1’ millimeter per hour latitude is equal to 1.84 kilometer (Robinson et a1., 1984). According to this estimation, the city is 8’xl.59 =12.72 13 kilometer wide in X-direction and 13’x 1.84 =23.92 ≈ 24 kilometer long in Y-direction. The total area of the city is 13 x 24 = 312 square kilometers. Two types of grids were made within the city area, coarse grid and fine grid. The dimension of coarse grid was taken 1km x 1 km that gave 13 horizontal and 24 vertical lines. The total numbers of coarse grid cells were 13 x 24 = 312 and the dimension of coarse grid was taken 100 m x 100 m, as the model can predict concentration for 100m road segment at a time. The station co-ordinate is (5565 m, 15640 m), which belongs to coarse grid number 201. Sub-grids of this coarse grid are prepared for calculation of local concentration. Calculating the concentration for each 100 sq meter grid, it is possible to calculate the concentration for Dhaka city.

There are different types of existing air quality models, such as Plume-rise models, Gaussian models, Semi-empirical models, Eulerian models, Lagrangian models, Chemical modules, Receptor models, Stochastic models etc. (Zanetti, 1993). Regarding the requirements for input data into the modelling tools, there are generally two main categories of information required (Moussiopoulos et al., 1996) and one of them is Emission. For the traffic models, typical descriptive information for the road network are required as input data. This could be number of cars per day, number of lanes, average driving speed, road gradient and explanation of the surroundings. And other one is Meteorology. The screening type models use default meteorology data as input, describing a critical meteorological situation. Other models use a set of meteorological cases as input, described in wind and stability classes. According to the study purpose, the Operational Street Pollution Model (OSPM) was chosen, which was developed for supplementation to standard monitoring activities and for assessment of abatement strategies at the National Environmental Research Institute (NERI) of Denmark. The model contains a simplified description of flow and dispersion conditions in urban roads. Concentrations of exhaust emissions are calculated using a combination of a plume model for the direct contribution and a box model for the re-circulating pollution part in the street. Despite the simplified parameterization, OSPM is capable of a proper simulation of the dependence of air pollution levels on meteorological conditions, such as wind speed and wind direction. A recent improvement is the modeling of turbulence in the street by taking into consideration the effect of atmospheric turbulence due to wind velocity, but also due to vehicle induced mixing, which dominates for low and calm wind cases. Using actual meteorological data and estimation of emissions, as well as a priori assumptions regarding flow and dispersion characteristics, the model provides hourly values of concentrations at predefined receptor locations in the examined street (Gokhale et. al., 2005).

OSPM typically considered (i) the shape and size of buildings and other obstacles, (ii) their position with regard to the wind direction, (iii) the variability in wind speeds and directions, (iv) the amount of mechanical turbulence mainly dependent on the vehicle induced mixing and the formation of air vortices because of the surface roughness, (v) the thermal turbulence effect, which is determined by the temperature structure of the lower atmosphere and relates to the vertical convection of heat. So OSPM can easily predict the concentration in street considering the effect of planning features on pollutant concentration. So using the OSPM, the changes have been observed while the street orientation changed considering the wind flow direction. It has been observed with the change of building height how effect the CO concentration and in what level. These factors are effecting the CO concentration in the study area.

In the parameterization of the OSPM, four types of data were needed and they are Topographical parameters, Vehicle parameters, Fuel parameters and finally environmental parameters. The topographical parameters were the size and shape of the buildings and other obstacles, surface roughness, the distance of the buildings from the road as well as the street width and length. Finally, the receptor height distance, road orientation etc. were collected from the field survey.

The next task was the specification of the diurnal traffic flow distribution for all types of vehicles. In this case, the input data consist of the traffic profile of the examined road segment, which has been created by the combination of the diurnal traffic flows for all vehicles and the vehicle type distribution that emerged from the manual counts. The amount and the kind of the observed traffic flows have prevented the formation of more realistic traffic profiles with detailed distribution for every hour or separate cases for weekdays and weekends and for different periods of the year. This shortcoming is actually the most important factor affecting the accuracy of the model outcome and thus, it's evaluation against the monitored emission levels. According to DUTP-II (1998), for last five years (1992-1997), the growth rate of motor vehicles in Bangladesh is 10% per year. As the traffic count survey was conducted in 2007 but the concentration data was available for the year 2003, so the traffic data was reduced according to the growth rate and the traffic flow for 2003 was predicted.

The basic emission factors are the functions of the average traffic speed. In the Street, which in our case is assumed to be 45km/h, i.e. approximately equal to the 30mph speed limit on Manik Mia Avenue. These expressions have been kept identical to the default data of WinOSPM (i.e for Danish conditions), since they are adopted in European level and can be used for Bangladesh conditions as well. In Bangladesh, EURO 1 has been used as emission factor in different researches. In this study, only the cold-start corrections have been excluded.

The second key category of WinOSPM input data involves meteorological and background pollution data. A user provided data file containing variables, such as wind speed and direction, the prevailing temperature and the global radiation levels created from the information of Meteorological station. The time coverage of these data was about 12 months, defining thus the duration of the simulation period. Three hourly data of temperature, wind speed, wind direction, relative humidity was obtained from the local meteorological station of Bangladesh Meteorological Department (BMD). These three hourly data were converted to hourly values by using a simple linear interpolation in excel program as the model requires the hourly values of these parameter. Center for Renewable Energy Research (RERC), University of Dhaka is recording the hourly value of global radiation and these hourly data were used in this study. The other background data were collected from the AQMP (Air Quality Monitoring Project) under the DoE (Department of Environment).

OSPM Evaluation

The Operational Street Pollution Model (OSPM) was evaluated for Dhaka City. The hourly street modeled value was 1.17 ppm and the background value is .942, which is 21 percent less than the modeled value, adopted from Continuous Air Monitoring Station (CAMS) and thus it was found that the model was working soundly for Dhaka city. Table 1 is adapted from the calculation window of WinOSPM and contains the summary of the input and output data after the model is run. From Table 1, it is clear that the model is working at a considerable label for Dhaka city. So farther this model can be used to estimate the CO concentration for another road segment easily by imputing the user provided hourly traffic data only. In this research, this model is being again used for another two road segments in Dhaka city.

Table 1: Win OSPM Results.

Street: Manik Mia Avenue ***Calculated on: 02/10/2008***
17:06:43
Average Daily Traffic: 68320 (calculated); User provided [C:\Program FIles\WinOSPM\Data\Traffic\National\Dhaka\MyTypeD2.txt
Emission Scenario year:2003
Period Covered (User Provided Meteorological Data): 01. January 2003 00:00 - 30. December 2003 23:00
Urban Background: User provided

Component:	Hourly				Max Daily 8 hours mean		Daily average			*Data Coverage (% of year)*
CO (ppm)	Mean	Max	90% -ile	99.8% -ile	Max	93.2% -ile	Max	90.4% -ile	98% -ile	
Street Modeled	1.17	3.13	2.61	2.85	2.56	2.36	2.15	1.76	2.1	**87.31**
Background	.942	2.5	1.98	2.3	2.1	1.89	1.79	1.42	1.65	**87.31**
BD Limit Value(2002)										75 (EU limit)

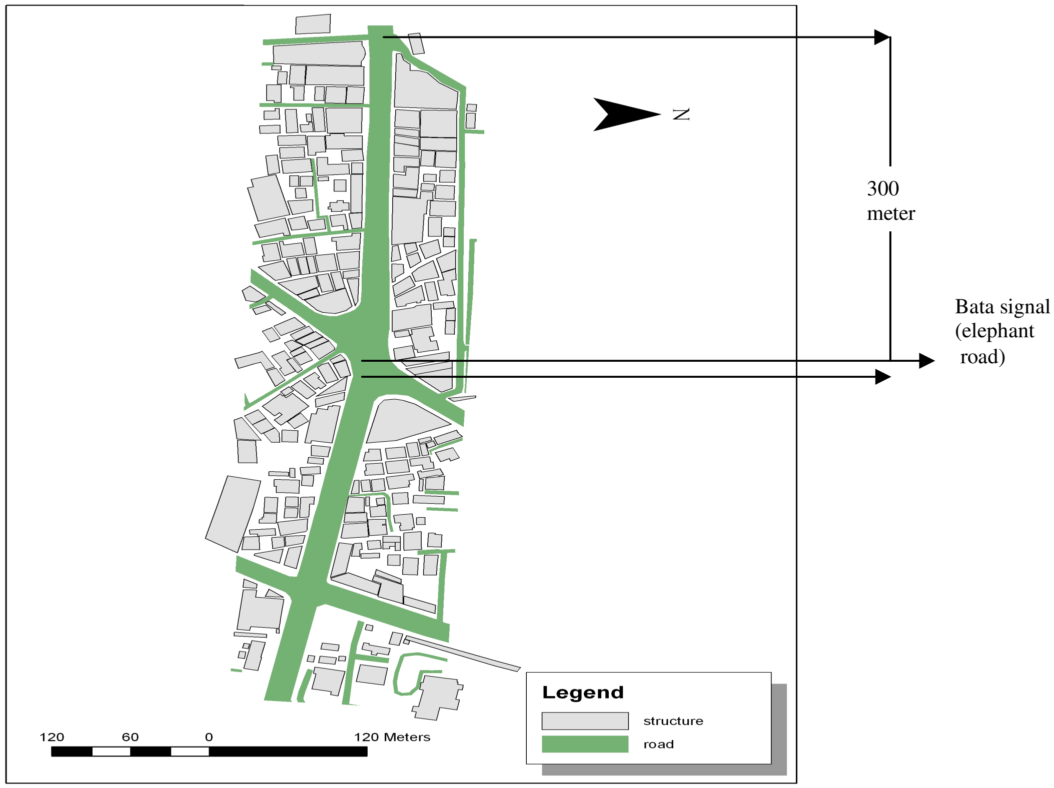
The effect of street canyon phenomenon on CO concentration has been pictured for two main factors. One is wind speed and direction and another is urban density and height of the buildings along the road, which derived a street as a street canyon. To conduct this analysis, a segment of road from Science lab to Bata more (elephant road) was considered. The road orientation is perpendicular to wind direction (east west direction). Whether the road is perpendicular or parallel has been decided based on the maximum wind flow direction for Dhaka city.

Effects of Building Height and Road Orientation on CO Concentration

From the view point of modifying the urban climate and human comfort by urban design, modification of the urban ventilation offers the greatest potential. The wind velocities at street level can be suppressed or increased according to the different comfort needs in different climate regions, by various urban design elements. In particular, urban elements as the orientation of the streets with respect to the wind direction, size, height and density of buildings, distribution of high-rise buildings etc. have great impacts on the urban wind condition.

Effect of building height and street orientation

In Dhaka, the major portion of wind flows from south direction or from south-west direction. The road segment orientation is east west direction (Figure 6). There are structures on both sides of the road. As major portion of wind is playing from the south direction, the building along the road stays perpendicular with the wind direction and acts as an obstacle for the general wind flow. As a result, the ventilation system in the road is poor. Again, the roof level wind which penetrates vertically in the road creates higher turbulences in the road space and causes higher concentration. This compliment has been proved by the WinOSPM changing the building height and the street orientation with the same vehicular flow.



Source: Google Image 2008

Fig. 6: Science lab to Bata Signal (elephant road)

In Figure 7, the red colored structures have been violating the existing height zoning. The road width is 60 feet. According to the height zoning, the maximum building height should not be more then 60 feet. But the red colored building possesses more than 60 feet height. Figure 8 show that the road side buildings create the road as road canyons. The average building height is 72 feet.

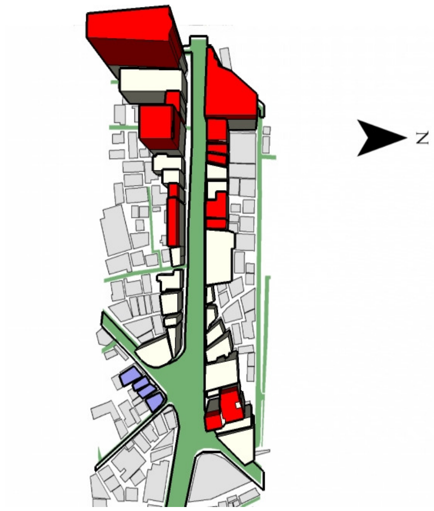


Fig. 7: Top view of the study area

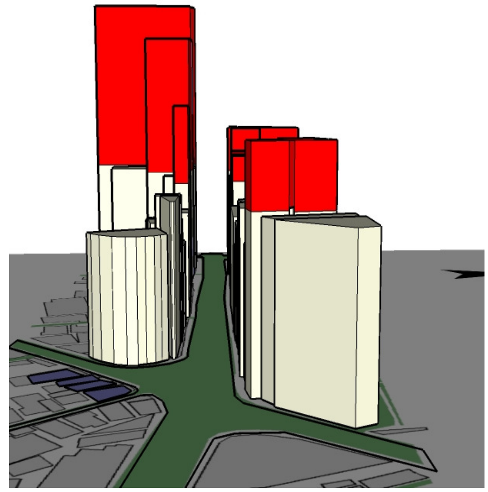


Fig. 8: Road view of the study area

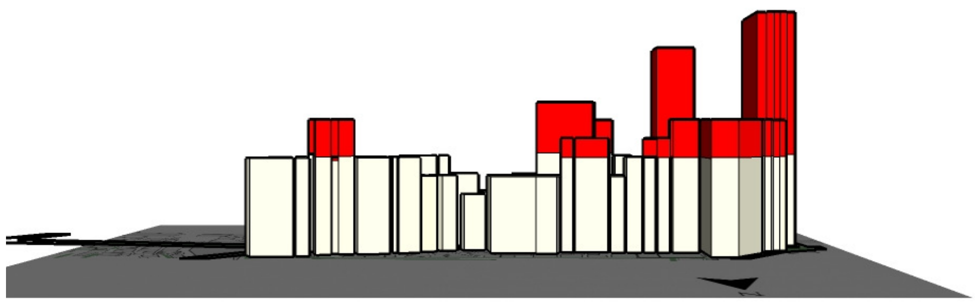


Fig. 9: Lateral view (north side) of the study area

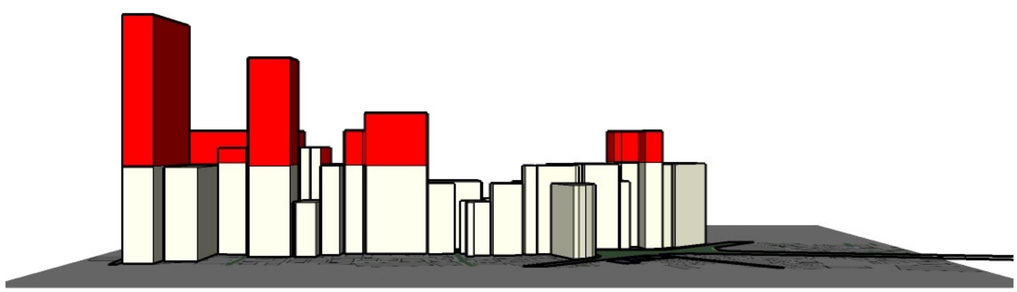


Fig. 10: Lateral view (south side) of the study area

From Figures 9 and10, it is clear that the road side buildings have been constructed violating the existing set back rules too, which results in inadequate space for air flow. This kind of road side development has been greatly hampering the urban road ventilation system and encouraging the roof level vertical wind flow in the road as well, which causes higher turbulence of wind in the road space resulting in higher concentration of CO in the road space.

Street orientation: east west (perpendicular to the wind direction)

OSPM model has been used for different urban features setup as well as for different street orientations. Two main effects on pollutant concentration have been assessed. One is different building height with the existing building density, and another is different orientations of roads considering the wind flow direction. Table 2 explains that in existing structure height and density the amount of hourly CO concentration for that 300 meter segment of road, with the existing orientation, is 1.82 ppm which results 43.68 ppm per day and exceeds the CO concentration standards for Dhaka city with a higher rate.

Table 2: the WinOSPM output considering street orientation (perpendicular to the wind direction) in different building heights.

Street name : Science lab to Bata more (elephant road)
Road length : 300 meter
Average daily traffic : 34,320 (calculated): user provided
Emission scenario year :2003
Period covered (user provided Meteorological data) : 01, January 2003 00:00 – 30 December 2003 23:00
Urban background : user provided

	Average building height along the road							
Component	7 - storied		6 - storied		5 - storied		4 - storied	
CO (ppm)	Hourly mean	Daily average	Hourly mean	Daily average	Hourly mean	Daily average	Hourly mean	Daily average
Street modeled	2.60	62.49	2.33	56.78	1.82	43.68	1.58	38.00

The major change in pollutant concentration has been observed with the 6-storied building height along the road space. The amount of hourly concentration is 2.33 ppm which is nearly 34 percent higher than that in the situation of 5-storied building along the road. If the building height increases to 7–storied, the concentration increases nearly 13 percent, which is relatively lower concentration rate than the concentration while6-storied building stays along the road.

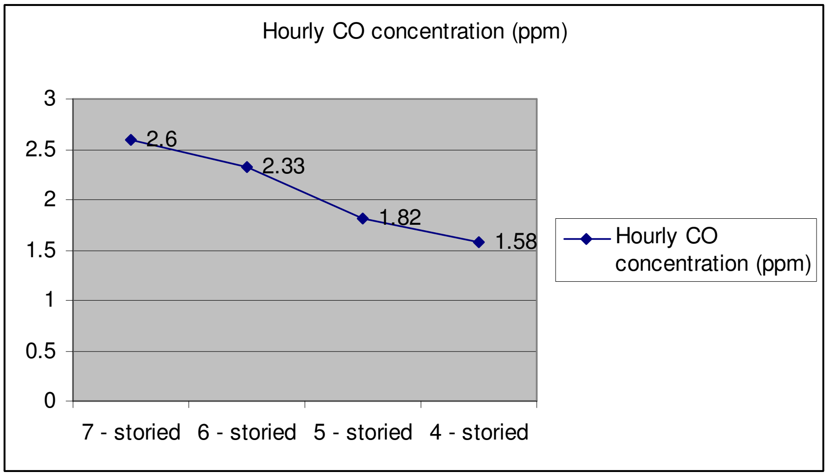


Fig. 11: CO concentration considering different building height

Similarly, if the building height is reduced to 4- storied, the concentration would be reduced with an amount of 12 percent. Finally, as per Figure 11, it is clear that if the road width is 60 feet then the building height should not exceed 60 feet which means that the violation of existing height zoning in the higher traffic concentration zone may cost higher.

Street orientation: north south (parallel to the wind direction):

Table 3: The Win OSPM output considering street orientation (parallel to the wind direction) in different building height.

Street name : Science lab to Bata more (elephant road) *Road length : 300 meter* *Average daily traffic : 34,320 (calculated): user provided* *Emission scenario year :2003* *Period covered (user provided Meteorological data) : 01, January 2003 00:00 – 30 December 2003 23:00* *Urban background : user provided*								
	Average building height along the road							
Component:	7 - storied		6 - storied		5 - storied		4 - storied	
CO (ppm)	Hourly mean	Daily average	Hourly mean	Daily average	Hourly mean	Daily average	Hourly mean	Daily average
Street modeled	1.64	39.12	1.59	38.30	1.41	34.07	1.33	31.99

Again if the street orientation is changed to north-south, parallel to the wind, a significant change in pollutant concentration would be observed. In such a case, the building height and density would become a weaker factor than the wind flow direction. From Table 3, it can be established that change in building height along the road results in very lower change in concentration level, but with the change of road orientation the concentration level changes at a higher percentage. Nearly 30 percent concentration will be reduced with the change of road orientation.

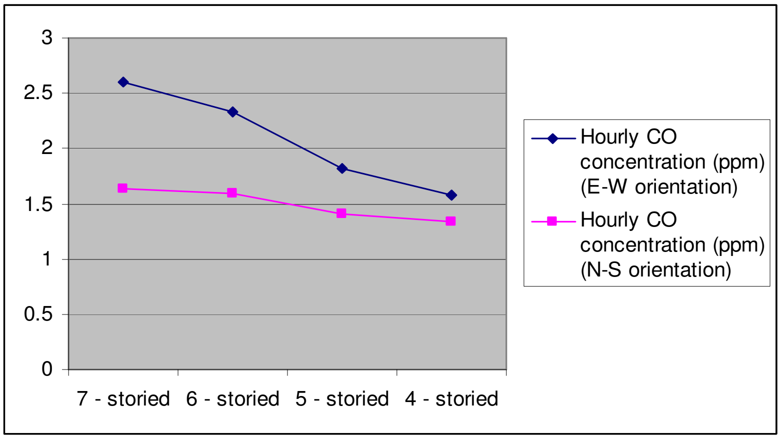


Fig. 12: CO concentration considering different building height and street orientation.

If the building height is changed to 6-storied, the concentration level will change only 12 percent where with the east-west road orientation, the change is observed as 34 percent. From Figure 12, it can be easily interpreted that the orientation has a great effect on the pollutant concentration. Road with north-south orientation possesses relatively lower level of CO concentration than the road with east-west orientation.

Discussion and Conclusion

This study presents the results of a limited monitoring and modeling methodology, which is adopted in order to understand the predominant mechanisms of pollution dispersion in an urban road canyon. The examined canyon in Elephant road area of Dhaka is relatively narrow and flanked by closely spaced buildings on both sides. Evidence of the street canyon effect on the diffusion of Carbon Monoxide emissions, hence, has been attempted to be established via the analysis of the measured levels and the results of the application of OSPM dispersion model. After parameterization of the OSPM for Dhaka city, the modeled value and the observed value was found highly correlated, which means the model is working soundly for Dhaka city. Due to time and resource constraints, the model predicts the CO concentration for only 300 meter of a road. By preparing the traffic database, inputting vehicle number (hourly) and speed, the CO concentration of any of the road of Dhaka city can be easily estimated. This study proves that with the increase of the building height along the road, the CO concentration also increases in the road spaces, and if the street orientation changes to perpendicular to parallel to wind flow direction, the concentration reduces also. Modifying the urban design by proper planning of the planning features or by stricter development control along the road (such as height zoning), the pollutant concentration can be substantially reduced. It is observed that the effect of planning features has a great effect on CO concentration in the road space. The road orientation also effects pollutant concentration.

There are some organizations working for the vehicular emission control in Dhaka City, such as Dhaka Metropolitan police, Department of Environment (DoE), Bangladesh Road Transport Authority. The building construction by the road sides is regulated by the RAJUK through the Building Construction Rules. This legal tool does not include any design control on the pollutant concentration. No other rules include any development control in reference to pollutant concentration. It has been clear in the research that by only controlling the vehicular emission of the road traffic, it is not possible to reduce pollutant concentration at an expected level. Planning control is seriously required in such a situation, which has to be given due consideration by the relevant authorities.

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