A Review on Indian Perspective
Air Pollution and Wind Environment Specifications

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ABSTRACT

This country report of India is a review of informations derived from different sources based on t various studies on air pollution, and mitigating efforts to control different levels of pollutants and pedestrian wind environment. The paper covers two aspects : (a) Successful implementation green initiatives taken by National Capital Regions (NCR) of Delhi to improve critical pollution conditions (b) Growing tall buildings in metro cities. The built environment around tall buildings has raised issues of pedestrian winds. In India the National Capital Regions (NCR) of Delhi including New townships and satellite centres such as Noida, Greater Noida, Ghaziabad, Faridabad and Gurgaon grew rapidly during past two decades. The changes in the geographical settings of the cities, the travel mode and behavior of transport, subsequently has increased demand on Infrastructure, Industrial growth, Waste handling & Management and pollution control are compelling factors on such issues in the National Policy making. Effective implementation of transport interventions caused a major challenge, however the cost benefits of these interventions are multidimensional. During the past decade, the government has introduced green initiatives to address the air pollution problem in the city. Still there remains a tremendous amount of potential to reduce the air pollution impacts due to the increase in demand for service infrastructure . While on the other side NCR and other metro cities are witnessing the increasing trend of tall buildings and it's impact due to winds in the vicinity of these high rise buildings. Winds are likely to also affect adversely the appeal of plazas, outdoor cafes, parks and pedestrian access-ways. Strong winds at ground level can make walking strenuous and even compromise the safety of people. This study presents proposal for criteria for pedestrian comfort and safety.

Key words: Air quality in NCR , Particulate pollution, health risk, comfort criteria, tall buildings

1. INTRODUCTION

The rapidly changing pattern of land use and industrial growth in India are essentially responsible for the issues and concerns about environmental risks. In the last two decades a rapidly expanding major cities in India, the demand for transportation, energy generation, construction of high rise building, waste generation, and industrial activity grew significantly. This is contributing to air pollution across the city borders. The transport sector is the fastest growing source of air pollution. In the view of this WHO estimates that more than 2 million people die worldwide every year from breathing in, tiny particles present in indoor and outdoor air. PM_{10} particles, which are particles of 10 micrometers or less, which can penetrate into the lungs and may enter the bloodstream, can cause heart disease, lung cancer, asthma, and acute lower respiratory infections. The WHO air quality guidelines for PM_{10} is 20 micrograms per cubic meter (μg/m^3) as an annual average, but the recent data illustrate that average PM_{10} in some cities has reached up to fifteen times than the desirable limits.

Over the past decade, a number of following green initiatives are introduced to address the issue of NCR pollution concern:

- All major public transport vehicles switch-over to compressed natural gas (CNG).
- Deployment of a sizeable number of CNG buses.
- Completion of Phase II Metro project
- Conversion of coal based thermal power plant to gas based power plants

Expandation of metro in the national capital region (NCR), with an increase of sizeable stakeholder has brought 10 percent degradation in the criteria of pollutants like RSPM and NOx by 2010 [1]. Delhi Metro became the first rail based methodology to garner 90,000 voluntary carbon credits for improving the efficiency of the power transmission in the system.

While another side enormous infrastructure in metro cities increasing trend of high rise building has raised daring concern of pedestrian comfort and safety issues. This drew an attention of wind engineers, urban designers, architects and urban planners in the counting, is witnessing an unprecedented growth of tall buildings in many of its metropolitan cities like, Mumbai, Delhi, Gurgaon, Ghaziabad, Greater Noida, Bangalore, Calcutta, Hyderabad and Ahmedabad. More than 1200 high rise buildings have already been constructed in Mumbai and more than 103 tall buildings with more than 30 storeys are presently under construction. Despite the proliferation of tall buildings in India, the Indian Wind Code [2] does not contain any references to pedestrian wind environment and there are no guidelines or criteria for assessing pedestrian winds. Several case studies have brought out [3] the occurrence of unacceptably strong building induced winds in the vicinity of tall buildings. The environment in the vicinity of tall buildings which has highlighted the prevalence of unacceptable wind conditions. The main objective of this paper to focus on Indian requirement to mitigate environmental risk in NCR and propose criteria for pedestrian comfort and safety.

2. Emissions Inventory for (NCR) Delhi (June, 2012)

Delhi, one of the largest mega cities of South Asia and the capital of India, is located at 28.5° N latitude and 77° E longitude and 216 m above mean sea level. In the last two decades, the city grew from being Delhi to National Capital Region (NCR) of Delhi, covering an area of ~1, 500 km^2, including 165 villages and 9 districts [4]. The NCR now includes new townships and satellite centers such as Noida, Gurgaon, Ghaziabad, and Faridabad, all of which are a combination of information technology firms and industrial clusters (the spatial spread of the city is presented in Fig. 2). In 2007, the population of NCR was found 16 million. It is expected to reach 22.5 million in 2025 (UN-HABITAT 2008).

The increasing demand of energy for domestic, transport and industrial sectors resulted in an enhance air pollutant emissions of particulate matter (PM), sulfur dioxide (SO2), nitrogen oxides (NOx), carbon monoxide (CO) and hydrocarbons. Since 1971 to 2001 the road network in Delhi increased by approximately 3.5 times, whereas the number of vehicles increased by 20 times [5]. The emissions inventory developed for all the criteria pollutants including PM_{10}, $PM_{2.5}$, NOx, SO_2, CO, VOCs and CO_2 is presented in Table.1.

Table.1 : An activity based emissions inventory (%) by sector of the national capital region of Delhi, India in 2010 [6]

	$PM_{2.5}$	PM_{10}	SO_2	NO_x	CO	VOC
Transport (TR)	26	18	3	67	28	63
Domestic (DOM)	11	7	6	1	11	6
DieselGenSets (DG)	5	3	3	17	6	9
Brick Kilns (BK)	13	9	11	1	11	7
Industries (IND)	13	9	23	8	14	4
Construction (CON)	4	6	1	1	1	1
Waste Burning (WB)	6	4	1	1	1	-
Road Dust (RD)	9	31	-	-	-	-
Power Plant (PP)	15	13	55	6	29	10

3. SOURCES OF AIR POLLUTION IN (NCR) DELHI

No single sector is responsible for Delhi 's air pollution. Rather, it is a combination of factors including industries, power plants, domestic combustion of coal and biomass, and transport (direct vehicle exhaust and indirect road dust) that contribute to air pollution. Seasonal changes in demand for fuel and natural pollution result in differing sources of air pollution in summer and winter. Among the various sources of air pollution, the transport sector, the fastest growing contributor, is one of the main culprits (if not the primary) causing air pollution in the urban centers of the developed and developing countries. In Asia, besides the economic hubs, the secondary cities, with population more than 2 million are increasing , the demand for personal transport is growing in all the cities, and those cities are increasingly facing the air pollution problems, especially from the transport sector.

In the transport sector, especially for the PM pollution, the diesel combustion dominates in number and quantity, primarily from the buses and the goods vehicles. Among the personal transport, the gasoline is the traditional fuel, but due to subsidy programs for diesel and the emerging engine technologies, the diesel component is increasing. Emissions from the CNG consumption during 2001-2009 have increased as follows (Fig. 1). While the vehicular emissions in Delhi during 2001-2009 GHGs From different vehicles shown in Fig .2.The percentage of motorized and non motorized transport in Delhi, India In percentage, trip share are following.

Cars = 12%; Taxis = 3%; Buses = 25%; 2Ws = 15%; 3Ws 50%; Metros = 4%; and the Non-motorized transport = 37%

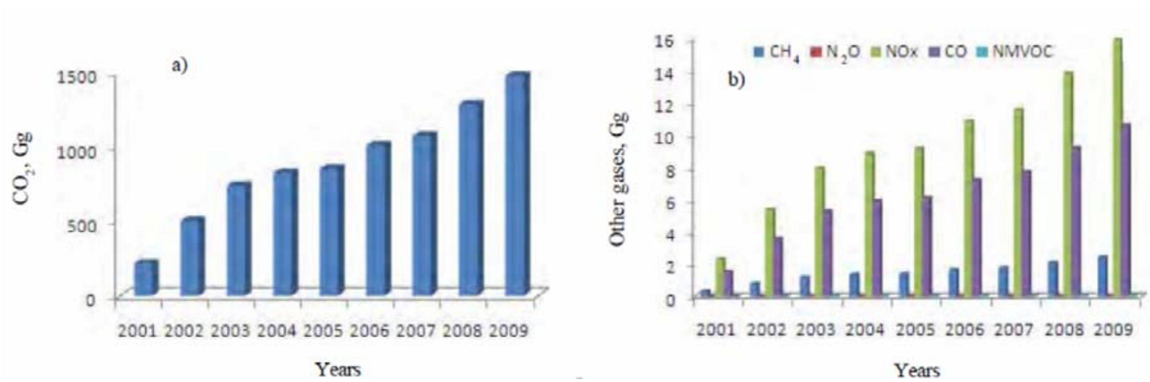

Fig. 1—Pollutant emissions from different vehicles categories: a) CO2; b) CH4; c) N2O; d) CO; e) NOx; and f) NMVOC [7]

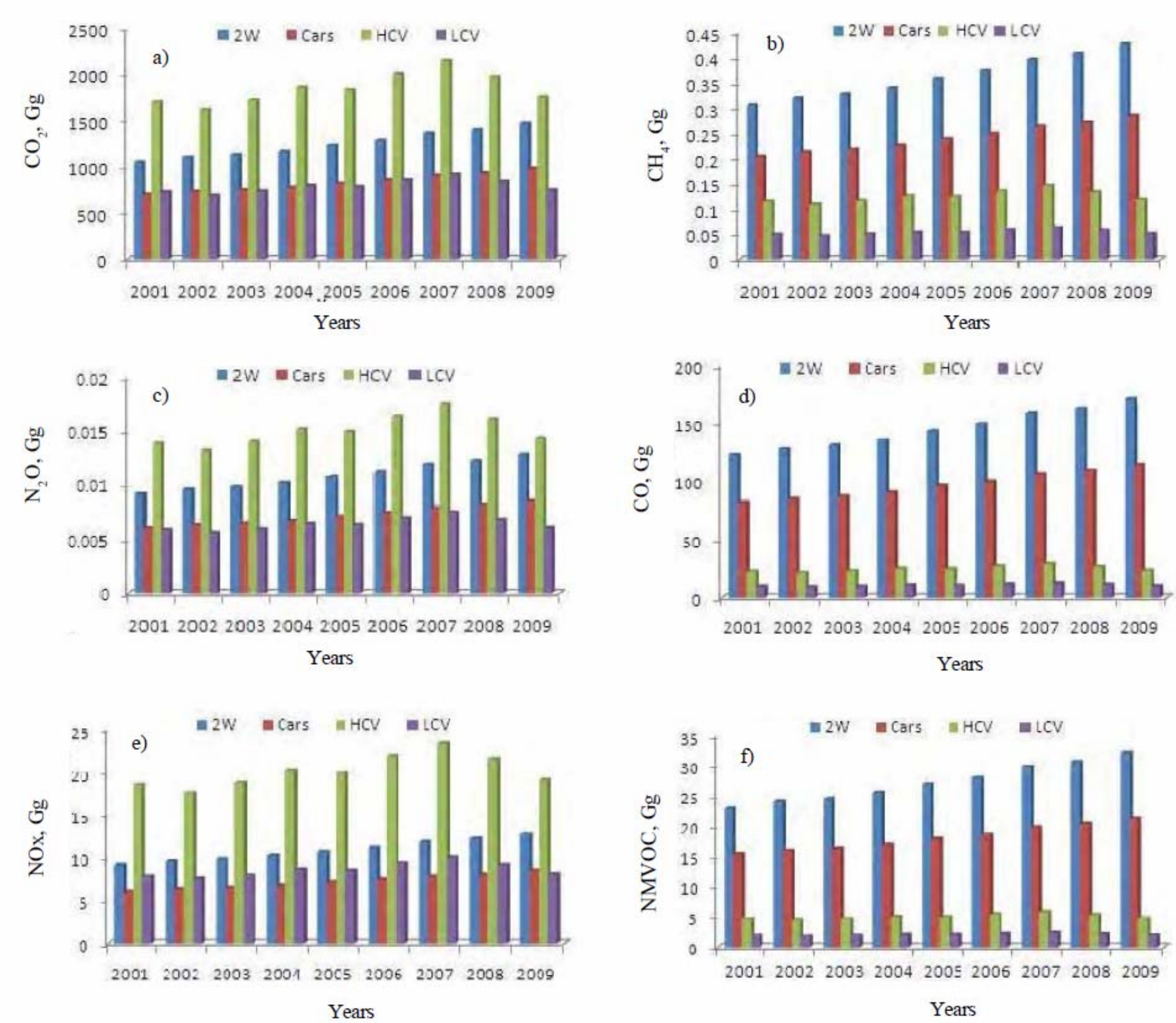

Fig.2—Pollutant emissions from CNG consumption: a) CO2; and b) CH4, N2O, NOx, CO & NMVOC [7]

Figure 2. Illustrates these differences in modal shares and [8] estimates that a large share of trips made in urban areas (especially in India) is less than 5 kms. This is a short enough distance for city officials to promote options such as NMT or public transport. The shares across the various models differ in cities depending on several factors.

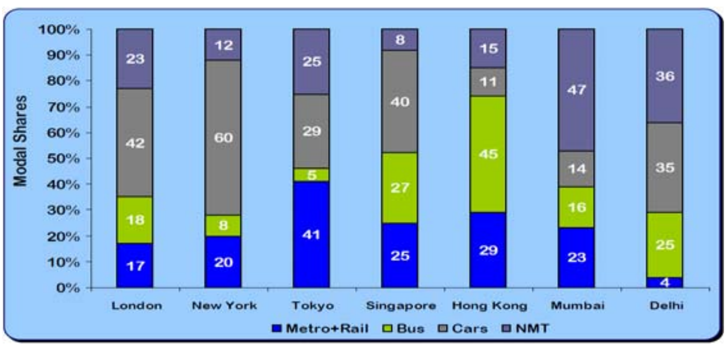

Figure.3. Percent Share Of trips in cities across the world [8]

4. CHRONOLOGY OF ACTIONS TO IMPROVE TRANSPORT SECTOR IN DELHI, INDIA [9]

1994-95: Unleaded gasoline
1996: 0.5% sulfur diesel; Govt. Vehicles convert to CNG
1996-97: 1160 industries closed or relocated
1998: Phasing out old Vehicle;Metro construction
1999: 0.25% sulfur diesel; truck during night time only
2000: Bharat-II; 0.05% sulfur diesel; old buses/3 Ws to CNG
2001-02: Full conversion of buses/3Ws/Taxis to CNG
2003: Supreme Court order for source apportionment
2006-07: Metro open in the North
2009: BRT opens, with limited success
2010: Metro Rail

5. INITIATIVES HAVE BEEN INTRODUCED TO THE NCR POLLUTION PROBLEM

Delhi (India), host city for the 2010 Commonwealth Games, covers an area of ~2, 500 square kilometers including parts of the neighboring states of Haryana, Uttar Pradesh, and Rajasthan. The area is collectively referred as the National Capital Region of Delhi (NCR). The region has grown rapidly over the past 20 year - in 1990, the total population of NCR stood at ~8.6 million and in 2011 at ~ 22 million (Census-India, 2012). As India's capital, Delhi has grown across all sectors - industry, transport, and housing – that have contributed to an increase in air pollution. This, in turn, has increased health risks, reflected by an increase in respiratory ailments.

The study domain covers Delhi and its satellite cities – Gurgaon, Noida, Greater Noida, Faridabad, and Ghaziabad, between 76.85°E to 77.65°E longitude and 28.2°N to 29.0°N latitude shown in Figure.3.

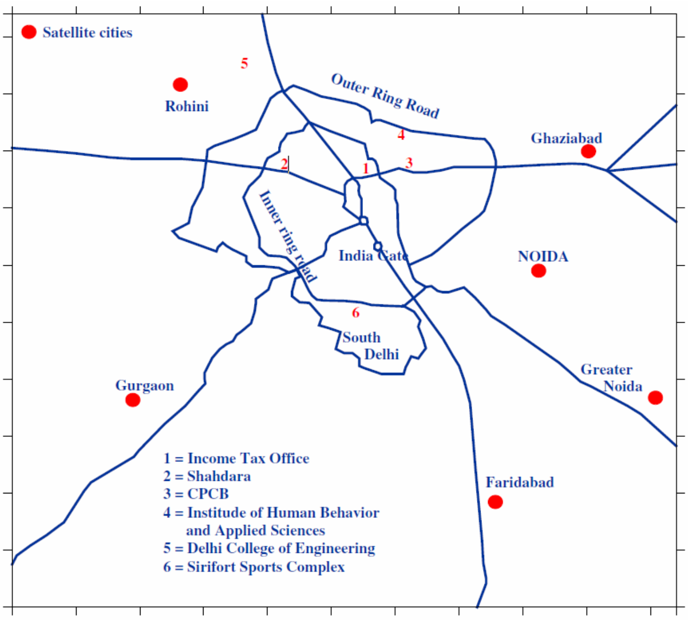

Fig. 4. A map of Delhi representing the ring roads and the approximate location of the continuous monitoring stations [10]

Number of green initiatives introduced to address NCR pollution problem [6]

- The largest ever compressed natural gas (CNG) switch for more than 100,000 public transport vehicles (buses, three wheelers, and taxis); the largest improvement coming from retrofitting approximately 3,000 diesel buses.
- Before the 2010 Commonwealth Games, a large part of the retrofitted fleet was replaced with newer CNG buses and the fleet size increased to around 5,000; along with implementation of special transport corridors during the Games, which succeeded as a pilot for future bus rapid transport application.
- The city also benefitted from the completion of the Metro Phase-II, increasing the coverage from 65 km in Phase I to 180 km, including an express line from the city center to the International Airport. This resulted in a drop in on-road vehicle density towards the satellite cities of Gurgaon and Noida.
- Conversion of coal based thermal power plants within Delhi to gas based power plants and relocation of the coal and fuel oil based industries, including brick kilns, to the city outskirts, following the Supreme Court orders.

These initiatives helped improve the quality of air in the city and thus the respiratory health for the citizens of Delhi, they have nevertheless fallen short in keeping up with the daunting challenges posed by the growing sources of air pollution. The benefits of leapfrogging to alternative fuels like CNG is outdone by the increasing number of passenger vehicles on road, lack of enough public transport buses, growing demand for electricity leading to use of in-situ generator sets, and industrial growth.

5.1. Effects of CNG implementation

Implementation of CNG leads to a considerable relative reduction in NO_x, PM, VOC and CO emissions whereas CH_4 shows an increasing tendency (Figure 4). This does not necessarily reflect a decrease in absolute emissions (given the increasing FC) but reflects what the emissions would have been if CNG had not been implemented [11].

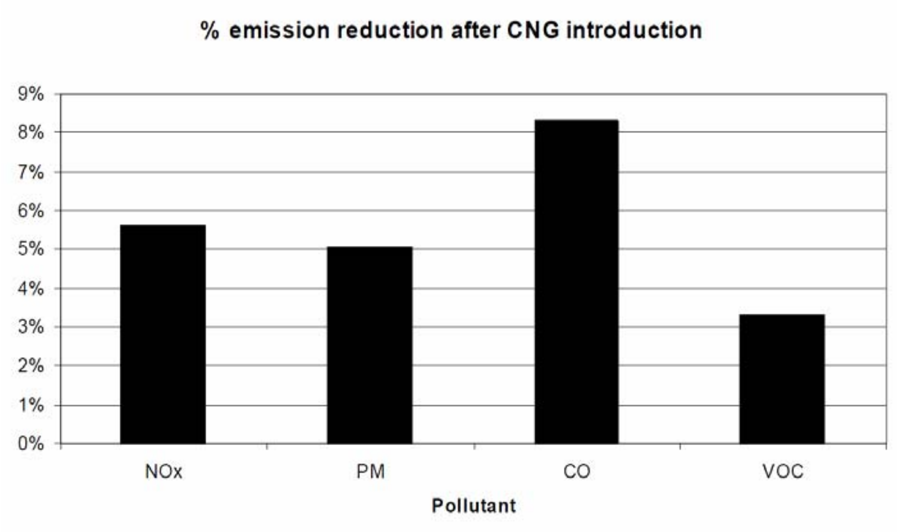

Figure.5. Relative emission reductions that can be attributed to the implementation of CNG in Delhi

5.2. Impact of Metro Rail in controlling air pollution in NCR

In India, successful metro/subway systems are operational in the cities of Mumbai and Kolkata, which carry the maximum of the public transport load, besides a wide network of on-road support and the new network in Delhi is expected to replicate that experience. Despite the recent construction woes, the Minister of Urban Development proclaimed that the Delhi Metro is the proudest achievement in modern India. Firstly, the Delhi Metro became the first rail based methodology to garner 90,000 voluntary carbon credits for improving the efficiency of the power transmission in the system. Secondly, a shift was also observed from a personal mode of transport to metro-rail, which results in a significant reduction in the emissions, estimated at ~7 percent of particulate and CO2 emissions on the road.

As the metro expands, with the expected growth in ridership, estimates suggest an immediate reduction of at least 10 percent in the criteria pollutants like RSPM and NOx in 2010. While the BRT and Metro Rail is effective in improving the traffic conditions and creating opportunities to shift people from personal to public transport, an equal emphasis should be given to promote walking and cycling – both to build a sense of community and a vibrant urban space as well as to promote movement of people that results in "zero emissions".

The Delhi government has taken considerable interest in improving the public transport system, they should also address the other sources such as industry and biomass burning to gain cost effective reductions. Policymakers increasingly recognize that addressing air quality as an urgent priority, primarily from the public health persp

ective.

Fewer vehicles and the decongestion for the residual traffic on Delhi roads due to Metro could lead to reduced air pollution. The monetary value of these pollution loads is estimated using the estimates of shadow prices of pollutants made in some recent studies in India [12,13] which are reported in the same table.

Table.2. Reduction in Vehicles Due to Metro (Phases I & II) [12,13]

Year	Cars & Jeeps	Two Wheelers	Buses	Total
2005-06	50586	284433	3398	338418
2010-11	80731	479286	4767	564784
2015-16	238737	1496497	12388	1747622
2020-21	381006	2521685	17374	2920065
2025-26	608055	4249185	24368	4881609
2030-31	970409	7160214	34178	8164711
2035-36	1548697	12065226	47936	13661859
2040-41	2471600	20330607	67233	22869440
2042-43	2979770	25049341	76975	28106087

6. COMFORT CRITERIA

Comfort criteria reflect our perception of the wind, which depends on what we are doing at the time. For e.g. when sitting and eating a meal at an outdoor café, we look for calmer conditions than we would for a brisk walk to work.

However it is not only the wind speed that matters but also its frequency and persistence. Both must be involved in the assessment, over a full range of wind directions. Over and above any question of comfort is that of safety. Strong winds have the potential to make walking difficult and even blow people over. The criteria therefore include a threshold wind speed above which vulnerable pedestrians might be at risk.

Table.3 : Estimates of Monetary Value of Pollution Reduction in the year 2011-12 due to the Metro [13]

Different Mode of Vehicles	Diverted Traffic	Annualized Cost of Conversion of Technology per Vehicle (Rs.)	Annualized Incremental Production Cost of Fuel per Vehicle (Rs.)	Monetary Value of Reduction in Pollution due to fewer Vehicle (Rs. millions)	Monetary Value of Reduction in Pollution due to Decongestion (Rs. millions)	Monetary Value of Total Reduction in Pollution (Rs. millions)
Bus	9450	17212	14790	302	11	314
Car	164252	5312	1876	1181	10	1191
Two-Wheeler	985789	4622	816	5360	18	5379
Total	1159491	27147	17482	6843	40	6883

Generally, criteria are given for some or all of the following conditions or categories.

1. Comfortable for long periods of sitting or standing
2. Comfortable for short periods of sitting or standing
3. Comfortable for walking
4. Uncomfortable for walking
5. Dangerous and unacceptable

The first four categories specify an upper limit and the last specifies a lower limit. [14]. The criteria developed by Tom Lawson at the University of Bristol are the most widely used in environmental impact assessment across the U.K. RWDI-Anemos and other reputed international wind consultants use the Lawson Criteria The definitions of discomfort levels and distress levels according to Lawson are as follows

<u>Discomfort Levels :</u> The onset of discomfort is defined separately for each activity in terms of an hourly-average wind speed which is exceeded for 5% of the time. The values are;

a) 10m/s for “Business Walking” by which is meant objective walking from A to B or for cycling.
b) 8m/s for “Pedestrian Walking.
c) 6m/s for “Pedestrian Standing” which is considered to be of long duration.
d) 4m/s for “Pedestrian Sitting” which is considered to be of long duration.

<u>Distress Levels:</u> The onset of distress is defined in terms of an hourly average wind speed which shall not be exceeded for 0.22% of the year or for 0.04% of any season. For areas in which the *general public* is allowed, the value of wind shall be 15m/s. In areas where it would be unreasonable to expect *sensitive* people or cyclists to be, the value is 20m/s.

Ratcliff and Peterka [15] carried out wind tunnel measurements of pedestrian wind speeds for nine building projects and evaluated them against the criteria put forward by Melbourne,1978 [16], Lawson and Penwarden, 1975 [17] and Isyumov and Davenport,1975 [18].

Most of the criteria proposed by researchers are subjective in nature and are based on the percent time that mean or peak hourly wind speeds are exceeded. Frequency of occurrence forms a major part in many criteria- for example, those of Davenport, 1972 [19], Penwarden, 1973 [20], Lawson and Penwarden, 1975 [16].

Flay, 1989 [21] proposed velocity criteria which vary in a continuous fashion with the probability of exceedance. Four performance categories (A to D) have been proposed for various activities along with typical locations. There is also a category E which is dangerous for pedestrian activity and this category is not permitted to occur in any development project in Auckland.

The Force Technology –DMI (Denmark) criteria is based on the threshold value of $\bar{u}$ = 5m/s, introduced by Penwarden in 1973 [20] and Penwarden and Wise in 1975 [22].

7. PROPOSED CRITERIA

The criteria proposed by Mohan, 2011b [23] give the acceptable wind speeds and their probability of occurrence for different activities and the areas where these activities would occur. Rather than specifying the limiting wind speeds and the probability of their occurrence for a limited percentage of time, the occurrence of acceptable wind speed for a particular activity for a major portion of the time are specified. This is in line with the recommendation given by Soligo et al., 1997 [24] and wind engineers from the world's most reputed wind engineering firm RWDI (Rowan, Williams, Davies and Irwin), who are of the opinion that clients, developers and architects find it easier to comprehend how often wind speeds should occur for the majority of the time rather than the probability of exceedance of certain limiting wind speeds for a small percentage of a time. The criteria comprises of four categories (A, B, C and D) for comfort and one category (E) for safety. The categories of comfort are specified for three major pedestrian activities like stationary long exposure, stationary short exposure and walking.

Category A wind speeds are applicable in areas where people spend long periods of time in leisurely activities like sitting/ standing in areas such as public open spaces, parks, outdoor cafes etc. The wind speed in such areas should be less than or equal to 2.5m/s for 90 percent of the time. This corresponds to Beaufort Number 2 (light breeze).

Category B wind speeds are applicable in areas where people spend short periods of time such as entrances to buildings, bus stands, window shopping etc. In such areas people would tolerate slightly higher wind speeds. The wind speed proposed in such areas is less than or equal to 4 m/s for 90 percent of the time. This corresponds to Beaufort Number 3 (gentle breeze).

Category C wind speeds are applicable in areas used for pedestrian movement such as pathways and public footpaths. The wind speed in such areas is proposed to be less than or equal to 5 m/s for 90 percent of the time. This corresponds to Beaufort Number 3 (gentle breeze).

Category D specifies that when the wind speeds exceed 5m/s for more than 10 percent of the time, people start experiencing discomfort. This is in line with the limit for the onset of discomfort as specified by Penwarden, 1973 [20]. This limit has been adopted by several countries like the United States, Denmark and the Netherlands in their wind codes.

(Category E). Gust speeds that are enough to blow people over have been estimated by various authors to be between 20m/s to 30 m/s [25]. The value proposed for safety is a representative value in the middle of this range, i.e. 25m/s. The GEM (Gust Equivalent Mean) corresponding to this speed is obtained by dividing the peak gust speed by a gust factor of 1.85 as suggested by Lawson, 1978 [26]. This proposed wind speed should not exceed 13.5 m/s for 0.1 percent of the time. As the threshold speed for safety are higher than for comfort ,≤the frequency of occurrence has been set at a much lower level of 0.1% of the time which corresponds to events that would occur once or twice per year. This is in line with the standard for pedestrian safety laid down by most researchers and regulating authorities in various countries and by ASCE, 2003 [25].

The proposed threshold wind speed for safety corresponds to Beaufort Number 6 (Strong Breeze). Near Gale conditions would occur in wind speeds corresponding to Beaufort Number 7, i.e. for speeds greater than 13.8m/s. Beaufort Number 8, which gives the range speed between 17.2 to 20.7 m /s, is the speed at which people would be blown over by the gusts. Table 4.0 gives the criteria for comfort and safety in terms of two characteristic wind speeds $\bar{U}$ (Mean Wind Speed) and U_{GEM} (Gust Equivalent Mean). U_{GEM} is obtained by dividing the gust wind speed by 1.85 to derive Gust Equivalent Mean.

Table .4. Proposed Criteria for Acceptable Winds for Pedestrian Comfort and Safety (Mean Wind Speed/Gust Equivalent mean Wind Speeds)

Category	Activity	Areas Applicable	Mean Wind Speed ($\bar{U}$) / Gust Equivalent mean wind speed (U_{GEM}) in m/s	Probability of occurrence
A Comfortable for long periods of sitting/standing	Stationary long exposure(sitting / standing)	Public open spaces, Outdoor cafes, gardens	≤ 2.5 m/s	> 90%
B Comfortable for short periods of sitting /standing	Stationary short exposure (sitting / standing)	Residential areas, entrances to buildings, recreational areas, window shopping, bus stands	≤ 4m/s	> 90%
C Comfortable for walking	Walking	Public footpaths, appropriate for cycling	≤ 5m/s	> 90%
D Uncomfortable			>5m/s	> 10%
E Severe			13.5m/s	> 0.1%

Note: Categories A to D are for pedestrian comfort and Category E is for pedestrian safety

Certain wind effects are more dependent on the mean wind speed such as moving ahead in the face of a steady wind, in outdoor cafes or lounging areas. In such areas the mean wind speed would be an appropriate indicator of comfort. However gust speeds are also important in certain circumstances, especially in areas where winds are very strong and people's balance is involved. Several studies have shown that the comfort and especially the safety of people are mostly affected by gusts .

The proposed criteria capture the effects of both mean wind speeds and gust speeds. The comfort and safety criteria are expressed in terms of mean wind speed and comparison is to be made with both the mean wind speed $\bar{U}$ as well as the Gust Equivalent Mean Speed U_{GEM} . In the event that either $\bar{U}$ or U_{GEM} exceeds the proposed threshold limit the area would be judged unacceptable for the intended activity. The gust equivalent mean wind speed is obtained by dividing the peak gust speed Û by 1.85, which is a representative gust factor as suggested by Lawson [26] and Û is the peak 3 second gust exceeded about every 5 to 10 minutes. Table 2.0 gives the criteria for comfort and safety in terms of gust wind speed. This criterion is to be used where gust wind speeds are available for the assessment of pedestrian comfort and safety.

The proposed peak gust speeds for Stationary long exposure and Stationary short exposure are proposed to be less than 4.6m/s and 7.5m/s for 90% of the time respectively. The gust speed for walking is proposed to be less than 9m/s for 90% of the time. Conditions would become uncomfortable when the gust wind speeds exceed 9m/s and the threshold gust speed for safety has been proposed as 25m/s not to be exceeded for 1% of the time. Though there is a certain amount of variation in the criteria with regard to comfort by various researchers there is very good agreement among most researchers regarding the threshold limit of 25m/s for pedestrian safety [25]. Here it may be mentioned that in certain areas frequented by cyclists and sensitive persons the threshold could be suitably lowered to 20m/s.

Table .6 gives a comparison of the proposed criteria with the criteria published by various researchers regulating authorities. The same information has been shown on the wind control categories graph giving the curves for different wind categories prepared by Flay [21] for the city of Auckland in Figure.6 The curves of the graph delineating the boundaries between the acceptable categories (A-D) and unacceptable (E) categories of wind performance are described by the Weibull expression:

$$P(>V) = e\left[1\left(\frac{V}{C}\right)^{K}\right] \qquad (1)$$

where V is the selected value on the horizontal axis, and P is the corresponding value of the vertical axis. The curves have been plotted with a Weibull parameter K=1.5. Even though the literature shows variation in the criteria with regard to the type of speeds chosen (mean or peak wind speeds) and the probability of occurrence, when compared on a probabilistic basis most of the published criteria and the proposed criteria are in good agreement.

Table.5. Proposed Criteria for Acceptable Winds for Pedestrian Comfort and Safety (Peak Gust Wind Speeds)

Category	Activity	Areas Applicable	Peak Gust Wind Speed (Û) in m/s	Probability of occurrence
A Comfortable for long periods of sitting/standing	Stationary long exposure(sitting /standing)	Public open spaces, Outdoor cafes, gardens	≤ 4.6 m/s	> 90%
B Comfortable for short periods of sitting /standing	Stationary short exposure (sitting / standing)	Residential areas, entrances to buildings, recreational areas, window shopping, bus stands	≤ 7.4m/s	>90%
C Comfortable for walking	Walking	Public footpaths, appropriate for cycling	≤ 9m/s	>90%
D Uncomfortable			>9m/s	> 10%
E Severe			25m/s	> 0.1%

Note: Categories A to D are for pedestrian comfort and Category E is for pedestrian safety

Table.6. Comparison of proposed criteria with published criteria

Name of the Researcher	Comfort Criteria for hourly wind speeds
Penwarden and Wise (1975) [22]	Onset of remedial action Ū=5m/s
Isyumov and Davenport (1975) [18]	A Long Ū=3.58m/s for T<1.5% and >5.37m/s for T<0.3% B Short Ū=5.37 m/s for T<1.5% and >7.61.37m/s for T<0.3% C Stroll Ū=3.58m/s for T<1.5% and >5.37m/s for T<0.3% D Walking Ū=5.37 m/s for T<1.5% and >7.61.37m/s for T<0.3% Unpleasant for all other cases Dangerous for Ū=15.22 m/s for T >0.02% of the time(year)
Lawson and Penwarden(1975) [17]	A Covered Area: Ū>3.35 for T<4% B Standing area: Ū>5.45 for T<4% C Walking area: Ū>7.9 5 for T<4% D Unacceptable: Ū>13.85for T<4%, Uncomfortable for all other cases
Hunt et al. (1976) [28]	Tolerable conditions and unaffected performance: Ū<6 m/s for T <10% Safe and sure walking: 9m/s for T< 1%
Melbourne (1978) [16]	Stationary long exposure: Ū>3.35 m/s for T= 0.002% of the time Stationary short exposure: Ū>6.5m/s for T= 0.002% of the time Walking: Ū>6.5m/s for T= 0.002% of the time Unacceptable for any activity: Ū>11.5/s for T= 0.002% of the time
Flay (1989)[21]	As shown on the graph
Soligo et al.(1997)[24]	Sitting: Ū<2.5m/s for T>80% Standing: Ū<3.9m/s for T>80% Walking: : Ū<5m/s for T>80% Uncomfortable: Ū>5 m/s for T>20% Severe: Ū>13.41m/s for T>0.1%
Lawson (1990) [27]	Pedestrian sitting: Ū>4m/s for T<5% Pedestrian standing: Ū>6m/s for T<5% Pedestrian walking: Ū>8m/s for T<5% Business walking: 10m/s for T<5m/s Onset of distress: T>15m/s for T<0.22 for general public and 20m/s for sensitive people or cyclists
Durgin (1997) [14]	Sitting for long periods: Ū>4.18m/s for T<2.6% Sitting for short periods: Ū>6.06 m/s for T<2.6% Walking: Ū>7.74m/s for T<2.6% Uncomfortable: Ū> 9.91m/s for T<2.6% Dangerous and unacceptable: Ū> 17.64m/s for T>0.01%
Force Technology (2002) [29]	A Stand or sit for long: : Ū> 5m/s for T<0.1% B Stand or sit for short : Ū> 5m/s for T<0.6% C Slow walk: Ū> 5m/s for T<23% D Quick walk: Ū> 5m/s for T<43% Very Unpleasant: Ū> 5m/s for T<53%
NEN 8100 [30]	Sitting: Ū> 5m/s for T<2.5% Strolling : Ū> 5m/s for T<5% Traversing: Ū> 5m/s for T<10% Dangerous: Ū> 15m/s for T> 0.3%
Mohan (2011b)[23]	Stand or sit for long: Ū≤2. 5m/s for T >90% Stand or sit for short : Ū≤ 4 m/s for T >90% Walking: Ū≤ 5 m/s for T >90% Uncomfortable: Ū >5 m/s for T >10%, Severe: U>13.5m/s for T>0.10%

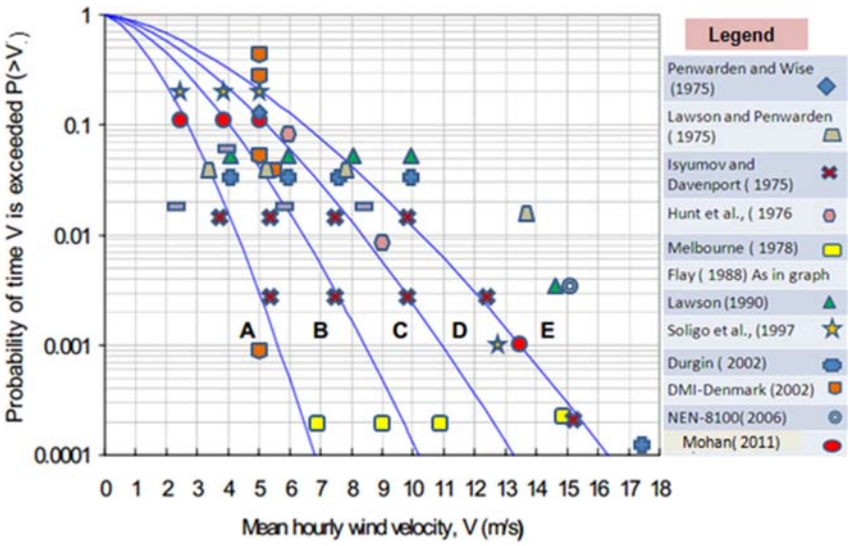

Figure.6. Pedestrian Wind Comfort Criteria Based on the Percentage Time Mean Wind Speeds Are Exceeded

CONCLUSION

Policy makers increasingly recognize that addressing air quality as an urgent priority, primarily from the public health perspective. In this concern various studies were included properly identifying the sources to formulate rational and effective policies and make informed investment decisions. Besides the capacity to make the investment decisions, it is important that the decisions are better communicated to the public for maximizing the possible benefits.

While the Delhi government has taken considerable interest in improving the public transport system, they should also address the other sources such as industry and biomass burning to gain cost effective reductions. The outcome of this study is intuitive. Policies that promote public transportation and allow for green initiatives result in lower pollution levels and lower greenhouse gas emissions. Promoting alternative transport options is not only environmentally sustainable but it is also a socially progressive policy. This study only captures the air pollution benefits, and does not even begin to quantify the various externalities that would spin off, including a more cohesive urban community, better health and equity.

The present study has also focused on the pedestrian level wind environment in the vicinity of tall buildings. An attempt has been made in the present study to understand various mechanisms of wind flow around buildings through wind tunnel investigations. Wind tunnel investigations have identified zones of wind speed amplification and stagnation. The purpose of the control is to avoid excessive wind velocity and turbulence in outdoor pedestrian spaces. The performance categories set tolerable wind levels for various pedestrian environments depending on the likely frequency and type of usage of those environments. They are designed to ensure that development does not make the existing wind condition significantly worse. The study has also explored the role of architectural elements and landscaping in mitigating the adverse effect arising from of vertical and horizontal wind flows.

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