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ORIGINAL ARTICLE

Pedestrian Wind Analysis for Indian Sub-Continent

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ABSTRACT – Urbanization in India is causing local wind and climate changes near high-rise buildings, affecting the urban wind climate pedestrian-level winds to dangerous and uncomfortable levels. Hence, today's architectural planning Wind comfort has to not only consider the wind load and internal conditions, but also must consider the outdoor wind building design environment. This study reviewed the methods of evaluating pedestrian-level wind weather, different Wind tunnel test standards of wind comfort, and various techniques for evaluating pedestrian-level wind speed. In the CFD Numerical following section, a brief overview of the current research on this topic and the way forward in India is Modeling related to the design and configuration of windward buildings at the pedestrian level. After analysing the previous documents, the authors recommend it is very necessary to homogenize the various wind standards, as it might have different consequences for planers. Among the various wind tunnel experimental technologies, compared to the hot wire wind speed measurement method, the Irwin probe's accuracy and simplicity is justified, and can be installed in multiple positions to measure wind speed horizontal of pedestrians at the same time. For the numerical simulation, several researchers have used the Renault medium Navier stokes-based technique, although the precision of this technique is not as good as the simulation of large eddies and the simulation of separate eddies. However, this technology is not only precise but also costs less due to its requirement of less computing resourcesl.

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INTRODUCTION

Urbanization, which manager the growing requirement for commercial as well as residential area, is a significant driver of a country's socioeconomic progress. Many cities in industrialized and emerging countries, such as Japan, Hong Kong, and China, provide as examples of the current situation. Malaysia and India are working to build a coherent nation. Mega tall skyscrapers or skyline constructions. Mega tall structures in metropolitan areas, on the other hand, have an impact on the micro environmental wind pattern and as a result on pedestrian wind (PLW) comfort. The construction of towering buildings in an urban landscape tends to divert high-speed wind from the top levels to the ground, creating circumstances that can be uncomfortable or even dangerous for pedestrians. Many such occurrences have been documented as a result of high winds. However, today's megacities are densely packed with high-rise structures, which have an impact on air flow. Because there is less air circulation at the pedestrian level, natural ventilation is compromised, allowing pollutants to collect at ground level, increasing air pollution. Winds like these may be seen in New Delhi, India, and Hong Kong, Tokyo [1]. Many deaths have been recorded as a result of the SARS(Severe Acute Respiratory Syndrome) accumulating in the air owing to a low wind velocity region at a construction premise in Hong Kong [2]. As a result, due to the presence of low wind speeds as well as high winds at building extremities, it is unavoidable to analyze wind conditions for pedestrian health. Many city governments have made it a requirement for big urban projects to analyze the pedestrian level wind environment during the early Stages of design [3–6].

On-site field measurements were used in the early stages of PLW speed measurement research. Because full-scale testing for the original design of a building project site is not practical, wind tunnel measurements on a scaled model allow researchers to examine the impact of changes in building design at the early stages of an urban project. In the beginning, PLW wind tunnel measurements were done with hot wire and film anemometers at a few sampling locations [7– 10]. Uematsu et al. [11] later created simple Omni-directional probes for measuring PLW velocity. With which the velocity of the pressure differential among tubes at scalable pedestrian altitudes and the tunnel boundary is calibrated. Given the accessibility of high accuracy real time-simultaneous pressure measurement sensors, the usage of Irwin probes has increased recently. In addition, the application of the sand particle erosion approach for similar investigations is less because it only offers objective data for the whole region under examination [12]. Other measurement techniques, such as laser Doppler anemometry (LDA) and scanning electron microscopy (sem velocimetry, have been employed to assess PLWspeed.

With the introduction of high-performance computer resources, the computational fluid dynamics (CFD) approach is also becoming a feasible tool for PLW research. Until recently, the stable Reynolds averaged Navier-Stokes (RANS) modelling technique, which needs less computational cost and time, has been effective. However, as compared to other

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high-cost approaches such as LES and DES, this methodology is less successful in predicting flow in low wind regions (deviation up to 5times).

The current study examines urban wind at the pedestrian level surrounding buildings in depth. This paper's material is arranged as follows: The method for assessing PLW climate with various wind comfort parameters is presented in the second part. The final section discusses the various methods for assessing pedestrian-level winds. The fourth section examines the impact of various building design parameters on PLW for a generic building layout. The last portion includes many research pertaining to the actual urban environment, such as the impact of building design criteria and basic recommendations for urban planning in response to pedestrian traffic.

ANALYSIS OF PLW CLIMATE AND COMFORT CRITERION

Method for Assessment of PLW Climate

(1) Empirical meteorological values from a local weather station; (2) aerodynamic data from the region; and (3) Mechanical wind-climate comfort parameters are used to determine a favourable wind condition for pedestrians [13]. The aerodynamic data aids in the computation of statistical data collected from a meteorological sensor at a specific building site. The modified data is then compared to the wind-climate comfort at this location. The process is illustrated schematically in Fig. 1. Hourly mean wind speed (U_{ms}, measured at 10 m height) and wind direction on open terrain ($y_{0,meteo} = 0.03m$) are among the meteorological data collected at the meteorological station. The likelihood of exceeding the threshold wind speed is calculated using the Weibull sampling distribution [14–16] based on the wind speed data collected from the weather station (1).

$$P(>U) = \exp\left[-\left(\frac{U}{c}\right)^{k}\right] \tag{1}$$

Where P (>U) denotes the likelihood of a wind speed above a certain threshold; U is the mean wind velocity strength at the construction site; c denotes the dispersion parameter; and k denotes the shape parameter. Matching Eq. (1) to the meteorological data yields these constants. Then, utilising aerodynamic data and the magnification factor R (Eq. (2)), statistical data must be converted to the region of interest. This magnification factor is made up of contributions from the design and the terrain (Eq. (3)) [16]. Alteration of empirical wind climatic information owing to local architectural design is part of the design input. Wind tunnel measurements or CFD modeling can be used to acquire these modifications. The entire research in this field is focused on evaluating design-related changes. Eq. (4) and Eq. (5) may be used to calculate the topography related modification.

It's difficult for developers, architects, and planners to pick a generic comfort standard because most of these criteria provide differing

$$R = U/U_{ms} \tag{2}$$

$$R = \frac{U}{U_{ms}} = \frac{U}{U_0} * \frac{U_0}{U_{ms}}, \tag{3}$$

$$\frac{U_0}{U_{ms}} = \frac{U_{site\ (at\ 1.75\ m)}}{U_{meteo(at\ 10\ m)}} = \frac{u^*_{site} \cdot ln\left(\frac{1.75\ m}{y_{0,\ site}} + 1\right)}{u^*_{meteo} \cdot ln\left(\frac{10\ m}{y_{0,\ meteo}} + 1\right)} \tag{4}$$

$$\frac{u^*_{site}}{u^*_{meteo}} = \left(\frac{y_{0,\ site}}{y_{0,\ meteo}}\right)^{0.0706} \tag{5}$$

Where U_0 is the reference wind speed at a certain distance upstream of the region of interest, without buildings, or at the computational domain's inlet; u_s*_{ite} and u_m*_{eteo} are the drag velocities at structure and meteorological recording station respectively; $y_{0,site}$ and $y_{0,meteo}$ are the aerodynamic surface roughness length at structure and meteorological recording station. Eq. (6) Isyumov [16] shows the relationship between the likelihood of exceedance and the amplification factor R.

$$P(>U) = \exp\left[-\left(\frac{U}{R^*c}\right)^{k}\right] \tag{6}$$

Wind comfort CRITERIA

Aside from wind velocity, the frequency with which it occurs is also important in determining wind comfort. As a result, the requirements for wind comfort include the maximum wind speed at which a pedestrian will feel uncomfortable, as well as the frequency with which this occurs. Earlier, a variety of wind comfort criterion based on threshold mean wind speed and likelihood of deviation [14,15,18–23] were presented. Figure 2 depicts the details of several wind comfort criteria, including the threshold mean wind speed (m/s) for various activities and the related exceedance probability (percentage). The majority of the criteria are based on the same likelihood of exceeding the cutoff wind speed for various pedestrian actions. While NEN 8100 [23] considers the same cutoff mean wind speed but a different likelihood of exceeding it. In Fig. 2, a typical wind environment for an Urban center (Palam Airport, New Delhi) is depicted, and the comparison of different wind comfort standards for different activities is displayed. This location is sensitive to excessive wind speed, which poses a hazard to pedestrians, as determined by comparison with the specified wind comfort standards, with the exception of Melbourne [14].

cutoff mean wind speed and exceedance probability. Various statistical analyses of wind comfort standards have been presented in this respect. Soligo et al. [20] translated the multiple wind comfort requirements on the same scale of incidence (20 percent) or for a specific activity based on discussions with developers and building managers. Soligo et al. [24] were also interested in standardising different wind comfort criteria.

However, none of the above-mentioned criteria took into account pedestrian discomfort caused by weak wind conditions in denselypopulated metropolitan locations. Durgin [25] suggested wind comfort parameters for cities with unfavourable wind patterns, such as Hong Kong, where wind comfort deteriorates throughout the hot and muggy seasons.

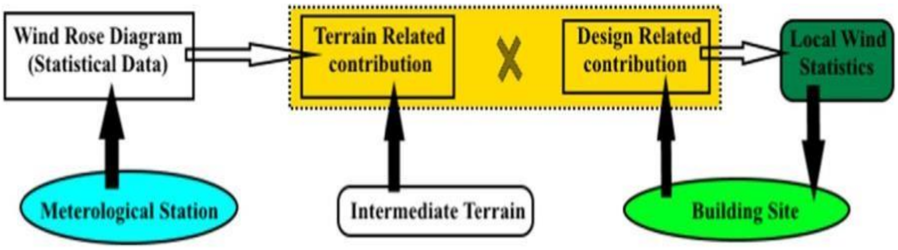


Figure 1. Wind comfort assessment flow

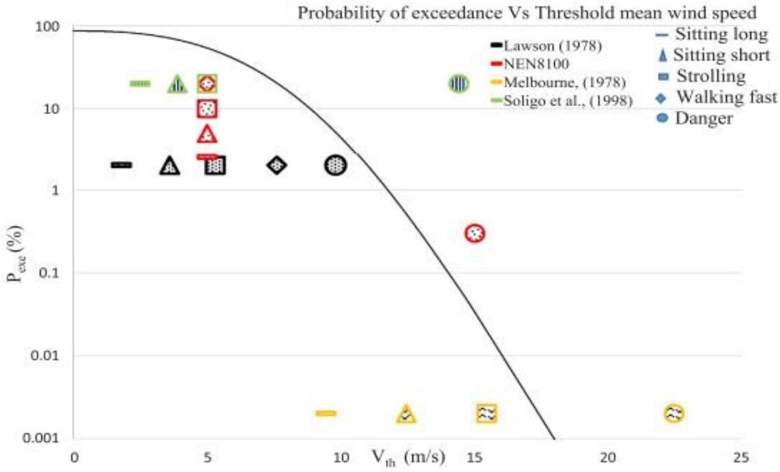


Figure 2. Comparison of various pedestrian wind criteria with emphasis Indian wind climate

Table 1. Wind comfort criteria based on overall mean veocity ratio (OMVR) representing weak wind conditions by [25]

Category	Threshold Velocity (Jun-Aug)	Threshold Velocity (Dec-Feb)	Exceedance Probability (%)	Activity	Remark
Unfavourable	OMVR<1.5Ur		50	N/A	No Noticeable Wind
Acceptable	OMVR<1.8Ur	OMVR<1.8Ur	2	Sitting long	Light Breeze
	OMVR<3.6Ur	OMVR<3.6Ur	2	Sitting sort	Gentle Breeze
	OMVR<5.3Ur	OMVR<5.3Ur	2	Strolling	Moderate breeze
Tolerable	OMVR<7.6Ur	OMVR<7.6Ur	2	Walking fast	Fresh breeze
Intolerable	OMVR>7.6Ur	OMVR>7.6Ur	2	No suitable Activity	Strong breeze
Danger	OMVR>15Ur	OMVR>15Ur	0.05	Dangerous	Gale

The total mean velocity ratio (OMVR) is used as limit parameter (Table 1), which reflects the combination of angular-positional values of mean velocity ratio ($MVR = U_P/U_r$), Where U_P is wind velocity at pedestrian level and U_r is wind velocity measured at 200 m altitude level.

MEASUREMENT TECHNIQUES FOR PEDESTRIAN LEVEL WIND SPEED

Field measurements in the actual urban setting, wind tunnel testing on a scaled model of the urban area, and CFD modelling are commonly used to produce design relevant contributions for the assessment of pedestrian level wind environment. Field measurement for urban development projects, however, is not viable to make modifications at the early design stage. The parts that follow go through the specifics of each approach as well as a comparative overall accuracy.

Methodologies for Analysis

Field Measurement

This approach is considered a reliable way for determining wind speed at limited places, and it has been utilised effectively by numerous studies [26–30]. This is usually done with a handheld three-cup-anemometer with a wind vane setup. The onset speed of this instrument is quite low, at 0.1 m/s, and it is very light [28]. The result of this equipment is one electrical pulse every rotation of the rotor, with the pulse rate adjusted to the wind speed. In the following part, we will compare this approach to others.

Wind tunnel

Hotwire/film anemometry (HWA, HFA), Irwin probes, thermistor anemometer, sand erosion, laser Doppler anemometry (LDA), infrared thermography, and particle image velocimetry are used in the wind tunnel for PLW investigations (PIV). Each approach is based on a separate underlying principle and a different experimental setting. It is beyond the focus of this research to describe each technique's operating mechanism, Table 2 simply discusses their applicability and capabilities.

Numerical Modeling techniques for PLW speed

Numerical modeling techniques for simulating PLW environments have lately gained a lot of favour among academicians and industrialists, thanks to advancements in computer hardware and software. One of the most significant advantages of numerical modeling over wind tunnel testing is that it provides precise flow field data for all involved parameters over the full computational domain. Furthermore, the necessity of similarity laws connected with wind tunnel investigation is not a restriction of numerical modeling. Majority studies, to model wind enviro-climate are based on the use of different RANS turbulence models e.g. Std. $k-\varepsilon$, Realizable $k-\varepsilon$ and RNG $k-\varepsilon$ model with standard values of prototype closure coefficients in simulation tools. However, the accuracy of CFD data is a serious challenge for acceptance, since it fails miserably in forecasting flow on the leeward side of the structure. As a result, CFD simulation results must be verified and validated [40]. The modeling results for PLW speed produced by std. $k-\varepsilon$ are similarly influenced for different prototype closure coefficients [2]. The reliability of CFD simulation is primarily determined by the turbulence model chosen. Table 3 summarises the capabilities and reliability of each turbulence model.

Table 2. Use of different wind tunnel technique by various authors and their pros. and cons.

Measurement Technique	Authors	Comments
HWA	[7], [8], [9], [10], [12], [31], [32], [33]	*Pros:* High-frequency response and high spatial resolution.
		Cons: Intrusive technique, only suitable for moderate turbulence intensity, insensitive to directional changes [33], [34].
HFA	[7], [9], [13], [26], [35], [36], [37], [38]	*Pros:* less susceptible to fouling and fragility, easy to clean, shorter sensing length, The agreement between wind tunnel and full-scale measurement is within 10% [26].
		Cons: Intrusive technique, only suitable for moderate turbulence intensity, insensitive to direction changes.
LDA	[37], [39]	*Pros:* Non-intrusive point-wise technique, allows measurement of high-turbulence intensity and calibration is not required. [40]
		Cons: This technique is costlier than HFA and HWA.
Infrared thermography	[10], [32], [37]	*Pros:* Non-intrusive Area technique, RMS, peak and spectrum value can be measured [37]
		Cons: Due to convection wind flow gets disturbed, sturdy and non-standard experimental set-up. No perfect correlation is obtained for temperature drop and wind speed [10]
PIV	[41], [42]	*Pros:* Non-intrusive area technique, high spatial resolution and directional sensitivity.

		Cons: Very expensive, sometimes dangerous, laser light shielding and reflection from buildings, not suitable for the cluster of buildings.
Erosion Technique	[12], [34], [42], [43], [44], [45]	*Pros:* Area technique, results are comparable to HWA for high wind speed [12]. For high turbulent flow, this technique agrees well with PIV measurements of mean wind speed [42].
		Cons: It is non-quantitative technique and difficult to ensure the repeatability.
Irwin Probes	[3], [46], [47], [48], [49], [50]	*Pros:* Allows measurements at numerous locations. No re-alignment for different wind direction. Simple in design and easy to operate [11].
		Cons: Less accurate for high turbulence intensity, it cannot accurately measure wind speed below 1.5 m/s [47].
Thermistor Anemometer	[51]	*Pros:* Small sensor size, susceptible to wind direction. The simple circuitry and low cost of thermistors make it economically feasible to operate the probes in large numbers.

Table 3. Use of different CFD technique by various authors and their pros. and cons.

Approximate Forms	**Authors**	**Comments**
Std.$k-\varepsilon$	[2], [44], [52], [53], [54], [55], [56], [57], [58]	*Pros:* Computationally efficient and economically viable. Agreement with wind tunnel measurement of wind speed is within 10% for regions with high wind speed ratio $(U/U0>1)$[59]
		Cons: Underestimates wind speed notably five times or more for low wind speed regions [59]. It cannot reproduce the reverse flow on the roof [60] and overpredicts turbulent kinetic energy in separated flows around windward corners of buildings [55].
Realizable$k-\varepsilon$	[6], [17], [50], [61], [62], [63], [64]	*Pros:* Sensitive to flow separation, reattachment and recirculation. For high wind speed region accuracy further improves as compared to std. $k-\varepsilon$ model [17].
		Cons: Less accurate compared to std. $k-\varepsilon$ model for low wind speed region due to underestimation of TKE in the wake region [17]
RNG$k-\varepsilon$	[65,81], [66], [67], [68,84]	*Pros:* For high wind speed region, accuracy improves as compared to std. $k-\varepsilon$ model. [59]
		Cons: Less accurate compared to std. $k-\varepsilon$ model for low wind speed region due to underestimation of TKE in the wake region [59].
LES	[69,85], [70,86], [71,87], [72,88]	*Pros:* Superiority of this method over steady RANS is clearly reported [60]. It can reproduce turbulence intensity and gustiness.
		Cons: Computationally very expensive as it requires more time and sensitive to many parameters such as sub-grid scale model, mesh resolution and time step size [73,89].
DES	[67,83]	*Pros:* Capable of producing similar results as LES with less computing time and lower mesh size.[74,90]discree
		Cons: Sensitive to parameters such as sub-grid scale model, mesh resolution and time step size and sampling time. [74]

Comparison of Different Techniques

Field measurement and wind tunnel measurement

Field measurements are appropriate for evaluating the PLW environment on an existing project site. Wind tunnel studies, on the other hand, are recommended for assessing the impact of modifications in the basic design of infrastructural development. Practical problems, such as range of interactions in atmospheric events, impediments due to cars, and so on, are commonly connected with comparisons of various approaches. At a project located in Toronto, Canada, Isyumov and Davenport [26] measured mean velocity in full-scale and in a wind tunnel. For windy areas, they observed a 10 percent agreement between full-scale and wind tunnel measurements. Janssen et al. [28] tested the results in a protected urban environment and discovered that the wind tunnel test under predicts the mean speed by 20% in even the most extreme areas. While Symov [30] noted that the comparison of these two approaches is reliant on the length of full-scale data collection, because longer-term wind speed data will accord well with the validation of the model.

Field measurement and cfd simulation

The numerical modelling approach offers data for the whole flow field, whereas field measurements can only be done at a few locations. However, correctly simulating wind environments with CFD methods is a difficult challenge. The results of CFD modeling at a university campus were compared [6]. Field measurement was conducted with 3D ultrasonic anemometers and the modeling was done with a realisable $k - \varepsilon$ model with standard wall function. The authors claim unequivocally that brief measurements of a few hours cannot be used as validation set because of the inherent unpredictability of climatic circumstances. At places where the variation of wind speed is considerable, there was a large discrepancy of 25% between measured and modeled mean wind speed. Furthermore, a slight movement in position might result in huge deviations when comparing wind speeds in high-gradient locations.

Wind tunnel measurement and cfd simulation

The numerical modeling has attracted wide acceptability and strong base due to the establishment of several standards and guidelines [75,91]. Wind tunnel investigation is often used for benchmarking numerical models and simulation outcomes. While use of RANS was found to provide quite accurate values for wind speed coefficients, however, it drastically underestimates wind velocity in the regions of slower wind speed coefficients [6].

Table 4. Various parametric studies to evaluate PLW around different building configuration

Parameter	Effect of Key parameter
Generic Building Configurations	
Permeable floor at mid-height of CAARC building [39]	The spatial extent of high wind speed reduces by using the permeable intermediate floor.
Corner modification of building [8]	Reduces the high wind speed zone near building corners.
Representation of PLW speed [31]	Quartile level (a) wind speed descriptor found to be a suitable indicator for evaluating PLW, as it avoids the problem of choosing gust factor.
Different building arrangement [65,81]	The arrangement with higher frontal aspect ratio and plan area density found to be suitable for natural ventilation.
Different grouping pattern of housing blocks [53]	The configuration in which buildings are arranged around a central space windward opened side facing the prevailing wind direction offer better ventilation.
Different building width and height for a single and row of buildings and use of podium [47]	Taller building improves ventilation near the building, Use of podium and width of building adversely affect ventilation.
Use of urban canopy layer [55]	Urban canopy layer worsens the ventilation than open street due to decrease roof ventilation.
Different street widths and podium heights [48]	High wind speed inside canyon for taller podiums.
Super tall buildings with unconventional shapes [51]	High-speed up ratio for super tall (400 m) buildings and mostly influenced by a change in building width at one-third level from the ground.
Building openings at pedestrian level of street canyon [54]	Buildings with permeability of 10% is adequate to improve PLW
Different layout of building pattern [56]	Configuration with square central space offers better PLW environment.
Wind twist angle, isolated building, wind incidence angle [78,94]	Displaced flow features and increased area of low wind speed at downstream of buildings. LWS region gets intensified with the increase of wind twist angle.
Wind twist angle, building dimensions and passage width [49]	Wind environment is asymmetric near the building, wind speed in the passage decreases with wind twist angle.

Passage between Two Buildings	
Passage width and height of one of the building [7]	Buildings with different height create most critical wind velocity condition.
Effect of wall function, Passage width between parallel buildings [57]	Horizontal inhomogeneity of wind profile affects the simulation results. Wind speed within the passages is only pronounced at the pedestrian level.
Passage width between two perpendicular buildings and building height [38]	Wind speed amplification in the diverging passage is often more than the converging passage.
Converging and diverging passage with 15° interval [58]	Converging passage with 15° for cold and temperate climate and diverging passage with 150° for the highly dense urban area in sub-tropical climates.
Converging and diverging passage for different angle 60°, 90° and 120° [41]	From ground to roof wind speed increases for converging case with increasing angle between buildings and decreases for the diverging case.
Lift up Building Design	
Lift up central core height and width [1]	Increase in the lift up core height mostly influences the area percentage of acceptable wind speed.
Lift up central core shape and building aspect ratio [3]	Speed-up ratio increases with building height, corner modification of central core controls the HWS zone.
Different building configuration (-, L, U, Square) [79,95]	Better PLW comfort than non-lift up building for oblique wind direction.
Building shape, separation orientation and turbulence model closure coefficients [2]	Square-shape arrangement yields higher average acceptable wind speed area, higher $C\mu$[b] and lower values for turbulent Prandtl numbers is suggested for accurate simulation.

[a] Quartile-level Wind speed- it is defined as wind speed that is being exceeded for 10% of the observation time.
[b] Model closure coefficient for Std. $k\text{–}\varepsilon$ model.

Reduced turbulence amplitude and prevailing wind fluctuation are two probable reasons for a high wind speed ratio, which are better simulated by the numerically RANS method.

The used of attrition to examine the PLW environment in Auckland's downtown area and contrasted degradation contour to Numerical simulations using the standard [44]. k model. The authors noticed changes where the wind contours were the greatest. The earliest degradation arises from the corner and sweeps across the constructions, according to Numerical simulations, whereas the wind tunnel demonstrates that the earliest degradation probably stems from the corner and sweeps across the constructions.

Parametric studies and their impact on generic building configuration

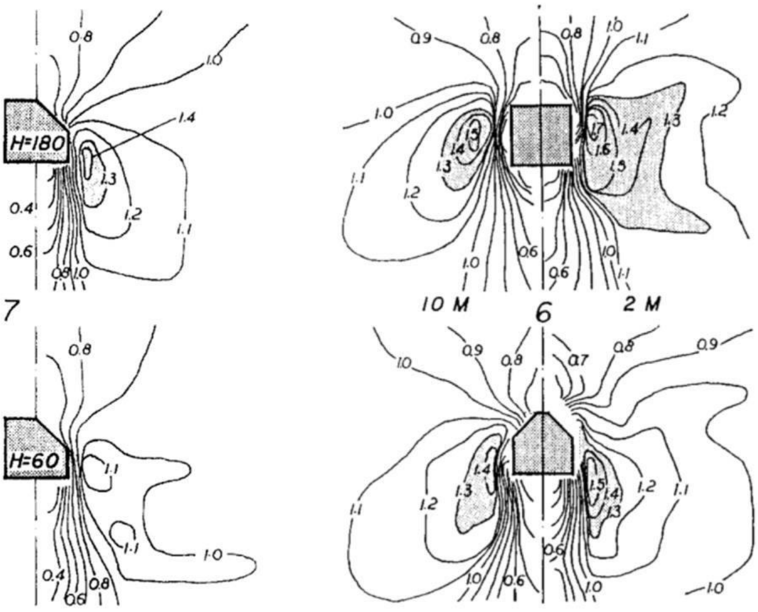
Different parametric researchers relate to the assessment of pedestrian level wind environment around conventional construction configurations have been done during the last decade, taking into account the influence of building height, shape, and layout of a group of buildings. Table 4 summarizes these researches. This section contains a brief examination of the impact of design factors on pedestrian movement.

HEIGHT AND WIDTH VARIATION

Due to the significant downwash effect, the maximum sustained winds velocity ratio increases as the height of the structure grows, as the taller building captures more upper-level wind and sends it to pedestrian level. As a result, it creates high wind speeds while also improving near-field air ventilation, as illustrated in Fig. 3.(a) [35,47,51]. The severity of turbulence, on the other hand, is unaffected by building height change [35]. Wider structures provide more protection from the entering wind, increasing the size of the low wind speed region on the structure's downstream face.

MODIFICATION OF CROSS-SECTION

Modifications in the structure's cross-section, such as tapering, rounding, and corner cutting, enhance the wind environment around the structure corners by reducing the size of the high wind speed region near the structure corners due to reduced divergence of flow separation, as illustrated in Fig. 3(b) [8,35]. However, owing to corner modifications, the root mean square value of the wind speed pattern is unchanged [8]. Due to decreased downwash, circular and polygon shaped cross-sections of buildings usually have better wind environment in terms of reduced strong wind zone as comparing to square-shaped buildings [35].



(a) (b)

Figure 3. Patterns of mean wind speed ratio for (a) height modifications [35] (b) Corner modifications [35].

MODIFICATION ALONG THE HEIGHT

Until date, Richards et al. [51] have looked into this adjustment in depth for various building models, and it has been suggested that changing the structure width at one-third height above the ground has a significant impact on the PLW atmosphere. The installation of a permeable floor at the structure's midpoint decreases the size of the high wind speed zone.Conversely, because this permeable floor allows upper-level wind to flow through the structure before approaching street level, it does not reduce overall wind speed ratio [39].

This layout has a central core that elevates the structure's structural framework from the ground, as well as a workaround for improving wind conditions surrounding the structure. Because of weaker downwash, this design change improves the area mean high wind speed ratio but lowers the area averaged low wind speed area on the leeward side of the structure [1,3].

Numerical model using the CFD programme Ansys/Fluent 17.0 was used to demonstrate the influence of this building design. The flow is governed by 3D steady-state Reynoldsaveraged NavierStokes models with a typical $k-\varepsilon$ turbulence model. For pedestrian level wind pattern, numerical simulation was performed following best practise standards [75]. The specifics of CFD simulation are not given since they are outside the scope of this report. Figure 4 shows the profiles of mean wind speed at pedestrian elevation for lift-up and traditional square structures as a consequence of this model. The descriptive results of the current modeling are comparable [1], which indicate higher wind speeds near the lift up region and lower values of low wind speed as relative to conventional building design. This aids in the improvement of circulation near the construction. Furthermore, the raise up space can be used for various functions such as a leisure area, parking, or pedestrian shelter. Furthermore, owing to an undesirable or high wind speed zone near the lift-up region, the usage of lift-up design of the building is constrained [76,92]. The flow via apertures on the structure's favourable and unfavourable pressure faces causes this unfavourable wind situation.

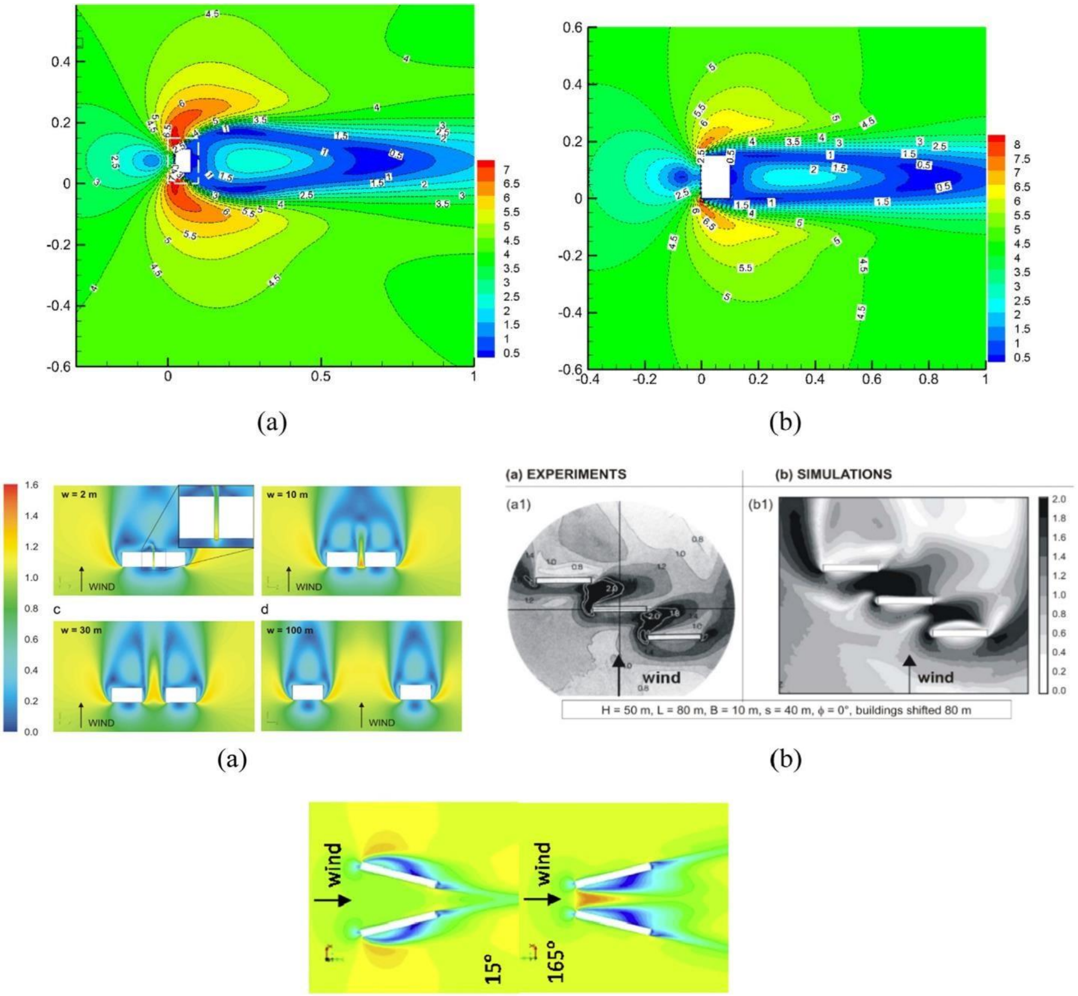
USE OF PODIUM STRUCTURE

Because the platform structure improves the spatiotemporal ex- tent of low wind speed zone close upstream and downstream of the building, it produces a shielding effect at pedestrian level wind flow close to the building and resulting in an undesired low wind speed zone at pedestrian level [47]. Podium structures are not advised in areas where natural circulation is necessary. Aside from that, the podium construction is thought to be utilised to shelter pedestrians from strong wind speeds.

DIFFERENT PASSAGES BETWEEN TWO BUILDINGS

As demonstrated in Fig. 5, the configuration of building structures, side by side, parallel, and angular (converging, diverging, and perpendicular), has a negative impact on PLW speed. The windiest scenario arises in the upstream corners when wind flow is perpendicular to the row of structures due to flow ducting and restrained horseshoe vortices [31]. As the distance between the structures grows, the channeling effect diminishes, and the flow becomes more independent of the distance between them.

As illustrated in Fig. 6 for the converging configuration, the windiest situation arises for the narrowest route and declines further for larger passage widths as the site moves further downstream (a). Whereas, since diverging passages do not provide wind protection, the wind speed ratio is generally significantly unfavorable than converging passages [38], and its value drops as route width increases, as illustrated in Fig.6.(b).



(a) (b)

(a) (b)

(C)

Figure 4. Wind Flow pattern with mean wind velocity (m/s) values at the pedestrian levels for (a) lifted building and (b) conventional building design

EFFECT OF BUILDINGS GROUP PATTERN

Different construction layouts control the microclimate of the metropolitan area in different ways in urban design. However, structure layout and design have a significant role in improving the PLW environment. According to several research [2,53,56], a layout with a square centre area and prevailing wind pattern toward the windward opening side face provides a superior PLW environment. As a result of this configuration's ability to efficiently restrict air flow disturbances.

EFFECT OF TWISTED WIND FLOW

The wind profile twists with significant angles in the lower section of the hilly terrain (below 500 m), shifting wind patterns along the way. As a result, in these settings, the wind-structure interaction is in engagement with the traditional profile is not the same to look into Tse et al. [77,93] studied the effect of convoluted wind flow on pedestrians by simulating such knotted wind profiles in boundary layer wind tunnel. The authors came to the conclusion that the dispersed kind of flow circumstances increases the geographical area of the low wind speed zone. With increasing wind twist angle, the size of the low wind speed region expands even more. Asymmetric flow patterns were discovered around two parallel structures.

Studies on Pedestrian environment around actual urban area

Below part discusses the overall flow behavior in the dynamic urban environment, as well as the impact of numerous factors on PLW speeds. The approach for assessing pedestrian comfort is also covered, as well as the essential considerations for designing urban development initiatives in accordance to pedestrian comfort.

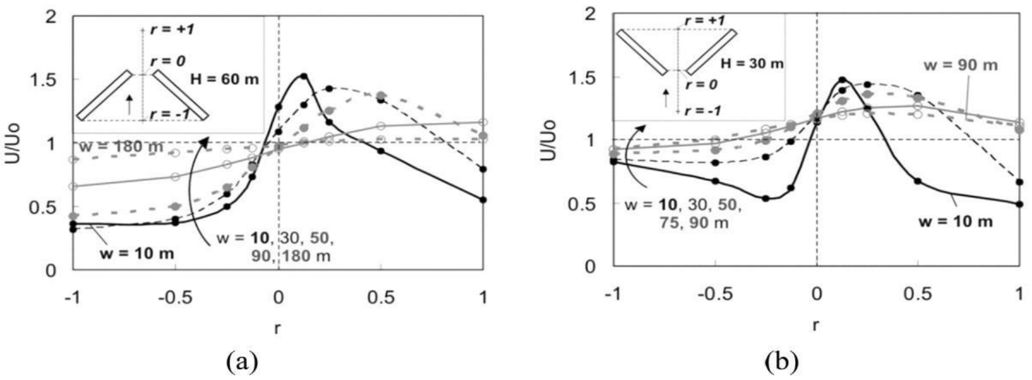


Figure 5. Variation of mean wind velocity ratio along pathway centre line for (a) Diverging passage [38] (b) Converging passage [38].

GENERAL FLOW CONDITIONS

When a high-rise structure is positioned upstream of a low-rise structure, the wind prefers to flow over the low-rise structure. Gusty winds are intercepted and redirected to street level by the proximity of towering buildings downstream [70,86]. The so-called venturi effect accelerates wind conditions within the gap between high rise buildings, resulting in strong wind movement, particularly at pedestrian level [57]. The use of a platform construction radiates gusty winds to the higher level, protecting pedestrians from harm [47]. These are the usual flow conditions that develop in an urban region as a result of various building layouts, as shown in Fig. 7.

EFFECT OF RELATED PARAMETERS

The coarse element and structure layout, such as breadth, height, building orientation, and density, have the greatest impact on air movement across the ground level. Due to higher friction close to the ground, it is thought that increasing building density lowers wind strength in an urban environment [80,96].

Stathopoulos and Wu [46] looked at how the spatial density of street system and the proportional height of structures affected the impact. The authors found that with increasing blockage ratio (RB, the proportion of approaching air flow trapped by a building block), wind speed along roadways decreased, and presented a simpler relationship for wind speed up ratio as Eq (7).They also concluded that, the maximum wind speed ratio increases with the height difference between reference and surrounding buildings. The narrow streets and uniform building height results in low wind speed [4].

$$\frac{U}{U_0} = 1 - 0.9R_B^{0.4} \qquad (7)$$

ASSESSMENT METHOD FOR PEDESTRIAN LEVEL WIND ENVIRONMENT

The majority of studies on the PLW environment use discrete point analysis to solve the problem [17,24,97]. Wind speed is measured at distinct sites in this approach. The appropriate wind comfort parameters are then applied to this wind speed. However, the pedestrian wind environment in an urban setting definitely differs geographically.

As a result, this form of discrete analysis is ineffective in meeting the objectives of urban planners in design [66]. Shi et al. [66,82] recommended that the realistic pedestrian wind comfort for urban planning design be space based in order to enhance the evaluation approach. The regionally averaged wind Vavg (Eq. (8)) and the maximum sustained winds speed Vmax in a plane were developed by the authors to assess pedestrian wind.

$$V_{avg} = \sum_{i=1}^{8}\left(a_i \frac{\sum_{j=1}^{n} V_j}{n}\right) \qquad (8)$$

In the above equation ai is the proportion of i-th wind direction; Vj is the wind velocity in j-th mesh grid; n is the total number of mesh grid in the plane. The above calculated wind speed should be within the specified limit defined in comfort criteria.

KEY FACTORS FOR URBAN DESIGN IN RESPONSE TO PEDESTRIAN COMFORT

For better pedestrian comfort below are the considerations which should be incorporated while designing urban areas in India:

1) To eliminate accumulated pollutants and enhance air circulation in hot and humid climates, roadways need to be oriented parallel to the existing wind pattern [4].

2) Usage of lift up structural plan [3] and a combination of buildings with a central open square space [2,56] improve ground level natural ventilation in high-temperature and low wind locations.
3) Corner adjusted structures [8,35] and a big stepped platform [47] surrounding the structure are useful for reducing higher wind velocities at the pedestrian levels in cold climate zones.
4) The PLW environment is primarily influenced by changes in building width at one-third level from the ground [51].
5) Taller buildings should be placed on the street's downhill side to capture more wind at the pedestrian level [4]. Furthermore, the inclusion of recreational areas and broad streets, as well as the removal of impediments to the flow of traffic around the city, enhances pedestrian comfort.
6) A appropriate wind comfort criteria, better topography mapping, and precise planning related modifications are needed during decision making in reply to pedestrian comfort.

CONCLUSION

The development of high-rise buildings in metropolitan areas significantly affects the wind environment. Eventually, it will be required to assess the wind environment during the early design phase of urban developments in order to recommend appropriate modifications to enhance the wind climate for pedestrians. It is either considered to limit high wind speed zones to reduce mechanical pressures on pedestrians or to promote natural outdoor air ventilation when planning urban areas. The current study examines the various wind comfort criteria for pedestrians as well as the measuring methodologies used to assess these wind speeds. The impact of various building design factors is further examined, and finally, the evaluation of urban wind at the pedestrian level and urban design considerations are explored. The following is a summary of the findings of this review research.

1) In urban planning, wind climatic statistics acquired from a local weather station are required for determining the building form, orientation, and alignment of roadways, and these wind statistics are evaluated with appropriate wind comfort criteria.
2) The likelihood of exceeding the threshold wind velocity at a certain location necessitates topographical and design modifications. Improved roughness mapping is necessary to get accurate terrain related modification. Otherwise, it may result in poor urban planning decisions.
3) Irwin probes give rather reliable data for design-related modifications and may be used at several sites for simultaneous assessment of mean wind speed and turbulence severity.
4) The steady RANS approach is the most cost-effective way to model a PLW environment, although LES and DES offer more accurate findings. The influence of alternative model closure coefficients has to be explored in depth to enhance the accuracy of stable RANS employing the standard $k-\varepsilon$ model.
5) Several building design characteristics, such as building height and breadth, have a negative impact on the PLW environment; however, building depth has no major impact on the PLW environment.

Furthermore, research based on various building groupings suggests that a layout with a square core area creates a superior PLW environment. Furthermore, the usage of lift-up buildings, podiums, and corner-modified structures provide a favorable design approach.

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The content of the paper presents a review of research work conducted by researchers from other parts of the world. A metaanalysis and subsequent recommendation of best investigation technique specific to Indian subcontinent has been proposed. The authors do not claim to have carried out the previous researches. The work done is duly acknowledged as per the references cited in the bibliography. And The research has been duly facilitated by the Department of Civil Engineering Graphic era university and State Key Laboratory of Disaster Prevention in Civil Engineering, Tongji University, China for funding the research study.

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