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MANIPULATION OF URBAN GEOMETRY TO ACHIEVE EFFECTIVE WIND FLOW FOR PEDESTRIAN THERMAL COMFORT: WITH SPECIAL REFERENCE TO URBAN DEVELOPMENT IN COLOMBO 4, SRI LANKA

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Abstract

The urban geometries create a physical character or structure at the street with relating to neighboring local climate. The urban geometry of a specific urban area has the potential to enhance or diminish the pedestrian thermal comfort by manipulating the urban climate and manipulates the behavior of wind by controlling the velocity and wind flow patterns. In such a context the design strategies of urban geometries must be implemented with in depth understanding and considering the pedestrians’ comfort. The research focus on how the existing urban geometries of selected site impact on wind flow which in reverse impact on pedestrian comfort and the impact of wind flow when these LCZ2 areas convert into LCZ1 areas. Height increase of the buildings and the density would not be an issue if the urban geometry is planned to avoid disturbance to natural wind flow and to maximize wind effects through urban canyons by manipulating H/W ratios. The research findings proved the buildings with high podiums does not help to increase pedestrian comfort in Sri Lankan climatic conditions; since the wind flow in this context is not very strong. The placement of open areas is critical as those could either increase or decrease the pedestrian thermal comfort. Hence, urban planning strategies should be ‘site specific’.

Keywords: *Urban microclimate, urban geometry, pedestrian comfort, Wind behavior*

1. Introduction

“The quality of life of millions of people living in cities can be improved if the factors that affect the urban microclimate are understood and the form of the built environment responds to them in an appropriate way. Underlying this belief is the notion that climatically responsive urban design is fundamental to sustainability. When the design of spaces between buildings is informed by the opportunities and constraints of the local climate, pedestrian comfort will be enhanced encouraging city dwellers to conduct more activity outdoors, and in turn to moderate their dependence on air-conditioned buildings and private vehicles.” (Evyatar Erell, David Perlmutter, Terry Williamson , 2011). Construction of a building changes the micro climate around it. Especially near the buildings with reasonable height, high wind speed is often introduced at the level of the pedestrians who may experience as unpleasant, even dangerous. Therefore, the design of a building should not focus only on the building envelope and to provide a good indoor environment but should also include the effect of design on the external environment. The external environment of a building, in particular those related to the wind, has received relatively less attention in the community of building physics. The relationship between the effects of wind, the wind comfort and wind climate should be discussed with respect to Sri Lankan tropical standards referring climatic data and building geometry in Colombo.

Urban climate is the micro-climatic environment which represents the interactions between urban areas and the atmosphere. Pedestrian comfort heavily depends on its geometry and the wind flow pattern. Sometimes predicted thermal sensation of this local climate will represent the uncomfortable range but street geometry can raise that uncomfortable ambience in to the range of neutral or slightly comfortable. So, the street canyon geometry plays an important role regarding pedestrian comfort with the impact of urban geometry driven wind flow. Four factors of pedestrian comfort are Temperature, Humidity, Mean Radiant Temperature and Air movement. In finding about the pedestrian physical comfort due to wind flow among urban geometry; Air movement is the main factor to be considered.

These outdoor climatic parameters should be considered in the critical situation. Critical outdoor temperature occurs from the end of March to April. But the main concern in this study is about Wind Velocities. Selected site at Colombo 4, is a coastal urban site located in Western Province of Sri Lanka. So considering the South western and Southern coastal wind flow during November to April in Sri Lanka, wind velocities and ambient temperatures are recorded at selected site. This research on pedestrian physical comfort due to urban geometry driven wind flow in Colombo will continue by taking that scenario in to consideration. The study is a research based simulation study to evaluate the effects of wind flow over urban geometry to enhance pedestrian thermal comfort, in an empirical manner and to explore the possibilities of manipulating built geometry to decrease outdoor temperature levels. The study focuses on manipulation of the urban geometry as a primary design strategy to enhance the pedestrian comfort by handling wind flow effectively.

2. Wind tunnel tests and Envi-met simulations

Wind Tunnel studies are carried out to observe the wind behavior around the buildings in a geometry or to evaluate structural wind loading on a building along with the theories of building aerodynamics. Wind tunnel tests are used to measure wind velocities and to evaluate the changes of micro-climatic conditions at a selected place due to the aerodynamics of tall buildings.

"As building designers were increasingly being confronted with the poor wind environment around their creations. The wind environment in pedestrian precincts around groups of tall buildings has brought in the greatest number of inquiries to the Building Research Station (BRS) in the sixties; some 200 inquiries were received between 1964 and 1970. A number of these have been studied in detail in the BRS wind tunnel in order to provide general information. Also studies of airflow around idealized model buildings have been conducted at the BRS." (Bert Blocken, Jan Carmeliet, 2003). (Figure: 1). In this study, wind tunnel test has been carried out to judge the wind behavior of a selected existing urban area, to assume the effective architectural strategies to manipulate buildings for further simulations studies via ENVI-met V4.

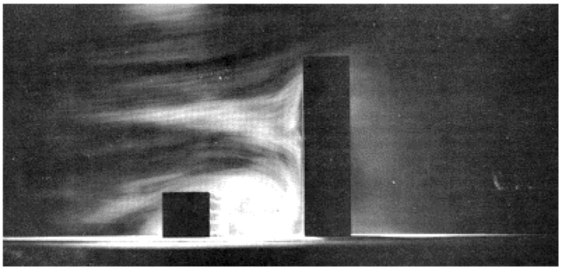


Figure 1: Smoke visualization test in a wind tunnel illustrating the flow around a slab block screened by a low building .Source: BRE, 2003

According to (S.Lenzholzer, J.Koh, 2010), it is the only software where all the factors influencing thermal comfort like wind speed and direction, and mean radiant temperature (MRT) are simulated integrally to derive thermal comfort indices. "It calculates the dynamics of microclimate during a diurnal cycle (24 to 48 hours) using the fundamental laws of fluid dynamics and thermodynamics. The model includes the simulation of flow around and between buildings, exchanges processes of heat and vapour at the ground and vertical surfaces, turbulence, exchange at vegetation and vegetation parameters, bioclimatology, particle dispersion." (The Hitchhiker's Guide to ENVI-met, 2016)

ENVI-met V4 software has three basic steps to proceed for activating the simulation. In this study ENVI-met V4 software was used to simulate the impact of wind behavior on urban canyons to modify the existing building micro climate to achieve pedestrian thermal comfort.

3. Research Problem

In the current context, Sri Lanka is at the starting point of massive vertical development projects; especially in the city of Colombo. Those major developments would mainly lie within the coastal wind flow in the near future. So, the coastal urban geometry driven wind flow is very important to consider when planning future vertical developments in ensuring pedestrian comfort in respect to tropical climatic conditions. The research questions on the most appropriate urban geometries which help to enhance pedestrian comfort by manipulating wind flows.

4. Research methodology

With the use of Colombo "Local Climatic Zone" map and the previous studies done by the researches, a specific case study area is identified and focused in to the compact mid-rise local climatic zone (LCZ2). LCZ2 category represents a dense mix of mid-rise buildings from 3 to 9 stories with few or no trees. Here brick, tile, and concrete are used as construction materials. Within these parameters, site at Colombo 4 is selected for the Calibration study; close to Majestic City and Unity Plaza buildings at Bambalapitiya, along with the Station Road connecting Galle Road and Sea Side Road. As the first step, an onsite survey was carried out to measure the Wind Velocities at the pedestrian height of 1.8m and at 3m by using Anemometers. In the same time the air temperatures at specific places were also measured by data loggers.

In parallel to the onsite investigation the climatic data of the specific dates were collected from the Department of Meteorology, to analyze the variations and to make relevant assumptions. Simultaneously a Wind Tunnel Test was conducted at a laboratory in the University of Moratuwa to study the wind behavior around the buildings in the existing environment of the selected site. With the findings of the wind tunnel test a base case simulation was carried out using ENVI-met to understand the existing climatic condition in the selected urban geometry. Validation was done by using field measurements, other collected climatic data and the results gained via ENVI-met simulations.

Five types of design strategies are tested for the same site by manipulating the Urban Geometry by considering the vertical urban developments to be taken place in the near future at coastal urban sites as such. Height to Width

Ratio and Floor Area Ratio is considered as key variables for above urban morphology manipulating options. The modifications are done in accordance with the present building regulations formulated by the Urban Development Authority (UDA). Analysis of the differences of Wind Velocities at pedestrian levels, Mean Radiant Temperature values and Leonardo contour maps which are obtained by the ENVI-met simulation process were conducted in respect to the modified urban geometries. With the results most effective architectural strategies to manipulate Urban Geometry in Coastal Urban Developments in Colombo in terms of enhancing Pedestrian Thermal Comfort are identified.

5. Simulation and Results:

Wind tunnel test was carried out on 5th April, 2016 at a laboratory in University of Moratuwa, using a scaled model of the selected site to understand and to analyse the wind behaviour over the urban canyon for the existing environment.

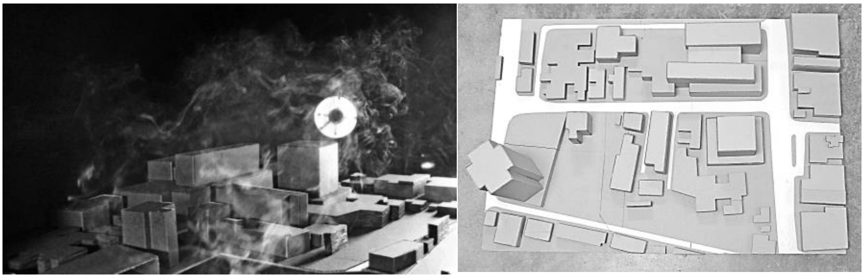
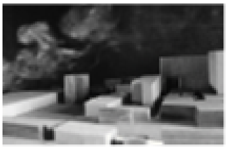
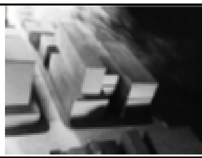


Figure 2 : Base case simulation

Through the wind tunnel tests conducted for the selected sites it made clear in selected sites majority of the wind particles flows freely over the canyon forming a combination of Wake interference flow, isolated roughness flow and Skimming flow of wind. When the building increases the wind flushes over the canopy and cause stepping effect. The existing geometry has caused downwind, wind turbulence effects, Low Bar Raw effect and Funneling effect due to varied forms of buildings whereas causes.

Wind Tunnel Test – Photographic Study

	Wind Behavior	Analysis
1		Majority of the wind particles flows freely over the canyon. It is a combination of Wake interference flow, Isolated roughness flow and Skimming flow of wind.
2		Wind flush over urban canopy causing Stepping effect with gradually increasing heights of buildings.
3		When the wind hits building surfaces, it causes downwind and wind turbulence effects.
4		Low Bar Raw effect happens at comparatively low and wide exposed windward facing building facades. Funneling effect causes along Station road.
5		When a comparatively high-rising building located in a mid-rise urban setting, if it lies along the wind direction, it helps to manipulate wind in different directions according to the shape. Multisided buildings such as this, are quite good to decrease downwash and to increase the distribution of wind over the canyon.

paration for Base Study (Simulation_1)

- Main model area, X grid = 75 / Y grid = 47 / Z grid= 30.
- Model rotation out of grid north = 342 degrees.
- Latitude 6.53 and Longitude 79.51, Reference Longitude 82.50 The cell area can be designated at any dimension from 0.5 meters to 10 meters. For selected sites, size of the grid cell is taken as (dx = 5m) x (dy = 5m) x (dz = 5m) as the minimum plot. Vegetation cover is not considered; since it is very minimal in LCZ2 conditions.

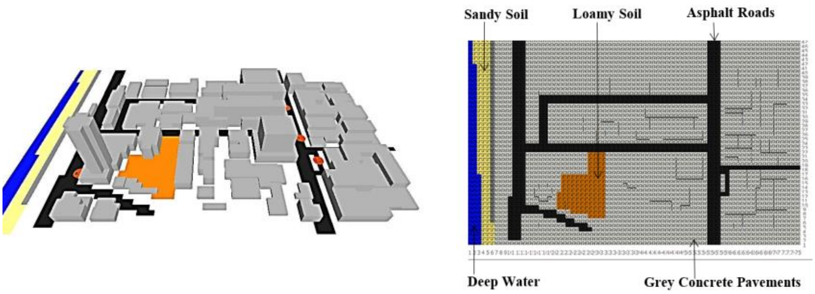


Figure 3: Building Geometry (Area Input file)of Simulation_1; Existing Condition. Source: Author

Modified Urban Geometries for ENVI-met Simulations

Manipulated Geometry_1 (Simulation_2)

Heights of the buildings are reduced. Maximum height of the buildings within the selected area is reduced to 18m (up to six stories).

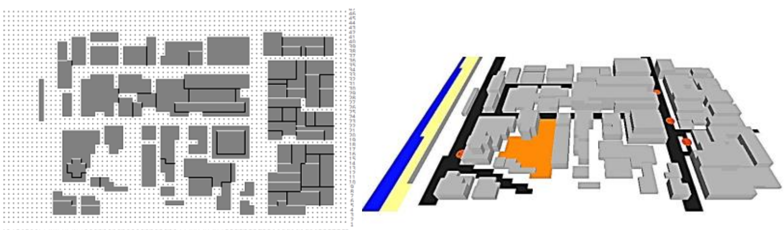


Figure 4: Building Geometry (Area Input file) of Simulation_2
Source: Author

When considering the manipulated urban geometry_1, this includes less tall buildings with fair amount of open areas. SVF for this urban canyon can be categorized as an Avenue Canyon which has H/W ratios less than 0.5. Floor area ratios and street widths are not changed. Soil and surface conditions used for the simulation is same as the Base case.

Manipulated Geometry_2 (Simulation_3)

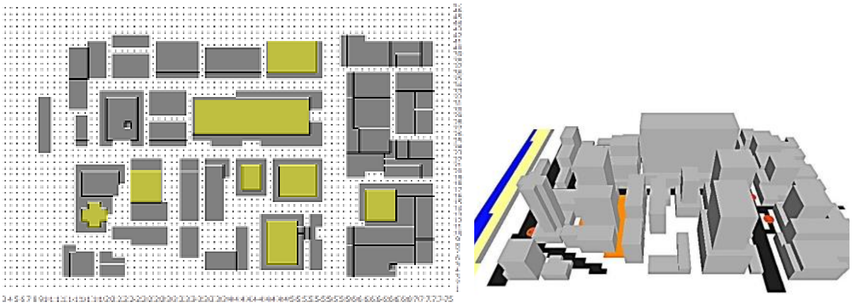


Figure 5 : Building Geometry (Area Input file) of Simulation_3
Source: Author

Heights of the buildings are increased. Majority of the buildings are around 30m in height. Number of taller buildings (45m to 70m) also increased within the selected area as highlighted in the figure 5. Street widths are not changed. Soil and surface conditions used for the simulation is same as the Base case. Majority of the buildings close to street edges are designed with a podium level as an architectural strategy. Those podiums are generally 10 - 20m in height. Some of the open areas are filled with building mass considering the urban development plan of Colombo 2020. When considering the manipulated urban geometry_2, this includes taller buildings with less amount of open areas. So the density of this area is very high. SVF for this urban canyon can be categorized as a Deep Canyon which has H/W ratios more than 2.

Manipulated Geometry_3 (Simulation_4)

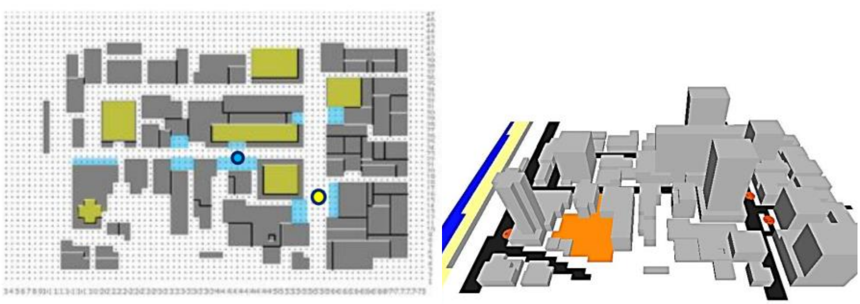
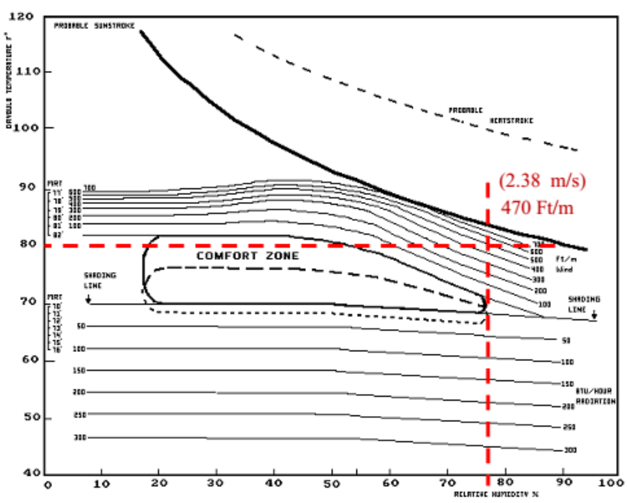


Figure 6: Introduced Open spaces + High-rise buildings & Building Geometry (Area Input file) of Simulation_4
Source: Author

Compared to Simulation_3, this has lesser number of taller buildings and more open areas. Building density is lower than in the Simulation_3, but higher than the Simulation_1 and 2. This includes 45 - 70m tall buildings which are positioned to direct wind flow into different directions, considering building design strategies as mentioned at section 2.2 in the dissertation. Those buildings are highlighted in yellow in figure: 6. Street widths has not changed. But adjoining open spaces are added along streets as shown in figure:6; highlighted in blue. Soil and surface conditions used for the simulation is same as the Base case. When considering Simulation_4, this is also having high density of buildings than in Simulations_1 and 2. SVF for this urban canyon can be categorized as either Regular canyons or Deep canyons depending on the H/W ratios at certain points of the street.

Analysis:
Analysis of Pedestrian Thermal Comfort via ENVI-met Simulations



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Source: Olgay's Bio Climatic Chart

Required Minimum Average Wind Speed to reach the level of Pedestrian Thermal Comfrot is 470 Ft/m (2.38 m/s), when the Relative Humidity is 78 and Temperature of 80 °F (26.6 °C) at the selected point.

Thermal Comfort Zone for Colombo is generally 24C◦ - 26C◦. Increase of wind speeds are helping to increase the area of thermal comfort zone as shown by figure: 8. Wind maps and Sections at receptor points, generated by ENVI-met LEONARDO tool, are used to analyze the wind behavior at urban geometries.

Therefor wind behavior at 10:00 hrs, 13:00 hrs and 16:00 hrs are taken into consideration in analyzing pedestrian thermal comfort during the day.

Wind Analysis for Base Case; Simulation_1

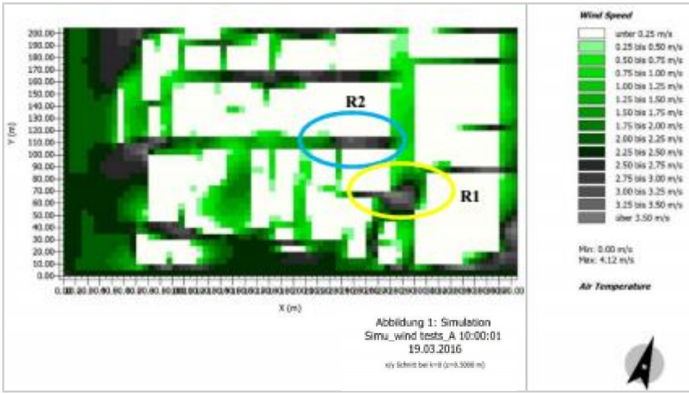

Figure 8: Receptor points - R1 & R2 , Simulation data via Leonardo tool. Source: Author

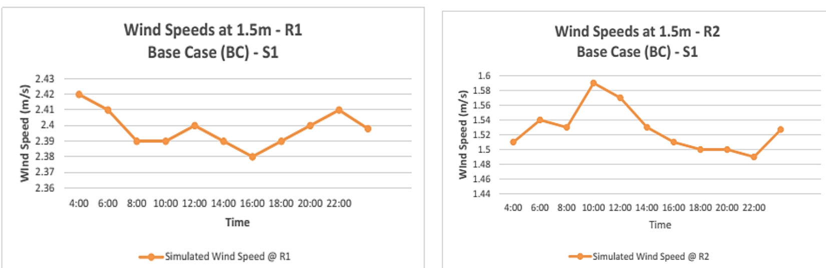

Figure 9 : Wind speed graphs at R1 & R2 for Simulation_1. Source: Author

Wind Analysis for Manipulated Geometry_1; Simulation_2

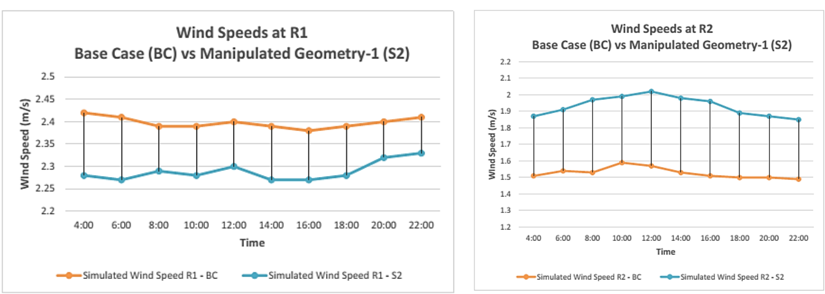

Figure 10 : Wind speed graphs at R1 & R2 for Simulation_2. Source: Author

Wind Analysis for Manipulated Geometry_2; Simulation_3

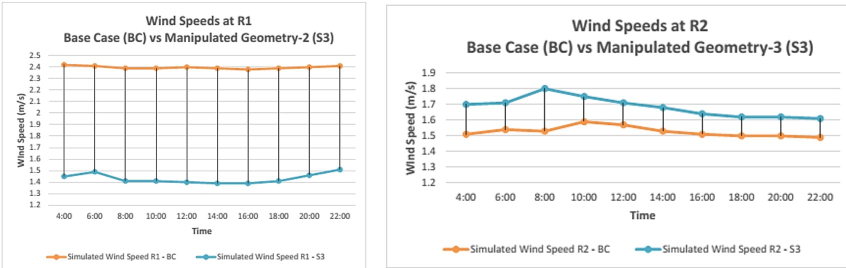

Figure 11 : Wind speed graphs at R1 & R2 for Simulation_3. Source: Author

Wind Analysis for Manipulated Geometry_3; Simulation_4

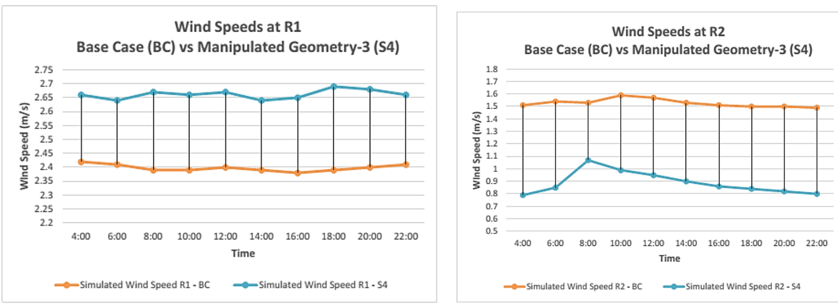

Figure 12 : Wind speed graphs at R1 & R2 for Simulation_4. Source: Author

Evaluation of Building Manipulations

Manipulated Geometry	Change of Average Wind Speed + −	Effect on **Pedestrian Thermal Comfort** (minimum of 470 Ft/m wind speed needs to reach comfort zones)
Simulation_2 **R1**	- 0.109 m/s - 21.5 Ft/m −	R1: 2.4 m/s - 0.109 m/s = 2.291 m/s (451 Ft/m) Not Comfortable. Yet closer to thermal comfort zone.
Simulation_2 **R2**	+ 0.404 m/s + 79.5 Ft/m +	R2: 1.53 m/s + 0.404 m/s = 1.934 m/s (381 Ft/m) Not Comfortable. But this helps to increase thermal comfort level at R2

Figure 13 : Evaluation of Building manipulations ***at Simulation_2***
Source: Author

Manipulated Geometry	Change of Average Wind Speed + -	Effect on **Pedestrian Thermal Comfort** (minimum of 470 Ft/m wind speed needs to reach comfort zones)
Simulation_3 **R1**	- 0.966 m/s - 190 Ft/m -	R1: 2.4 m/s - 0.966 m/s = 1.434 m/s (282 Ft/m) Not Comfortable. This creates a very uncomfortable atmosphere.
Simulation_3 **R2**	+ 0.157 m/s + 31 Ft/m +	R2: 1.53 m/s + 0.157 m/s = 1.687 m/s (332 Ft/m) Not Comfortable. Slight increase of average wind speed.

Figure 14 : Evaluation of Building manipulations ***at Simulation_3***
Source: Author

Manipulated Geometry	Change of Average Wind Speed + -	Effect on **Pedestrian Thermal Comfort** (minimum of 470 Ft/m wind speed needs to reach comfort zones)
Simulation_4 **R1**	+ 0.264 m/s + 52 Ft/m +	R1: 2.4 m/s + 0.264 m/s = 2.664 m/s (524 Ft/m) Comfortable. This atmosphere is Comfortable for Pedestrians, up to air temperature of 83°F (28.5 °C)
Simulation_4 **R2**	- 0.640 m/s - 126 Ft/m -	R2: 1.53 m/s - 0.640 m/s = 0.89 m/s (176 Ft/m) Not Comfortable. Slight increase of average wind speed.

Figure 15 : Evaluation of Building manipulations ***at Simulation_4***
Source: Author

Conclusion:

As observed through the results, manipulating buildings can be applied to achieve pedestrian thermal comfort goals in Colombo metropolitan area. When considering the urban development proposals for Colombo, LCZ2 areas would be converted in to LCZ1 areas in the near future. LCZ1 areas will consist of dense set of tall buildings with land cover of mostly paved. In such a context height increase of the buildings and the density would not be an issue if the urban geometry is planned to avoid disturbance to natural wind flow and to maximize wind effects such as funneling and channeling through urban canyons by manipulating H/W ratios.

Buildings with podiums are considered as a good pedestrian friendly design strategy for many countries due to the high wind speeds they have. According to the available literature countries in between the Tropic of Cancer and Arctic Circle, Tropic of Capricorn and Antarctic Circle are getting strong average wind speeds. Thus the downwashes due to those strong winds cause discomfort for pedestrians. Yet, since in Sri Lankan context no such strong winds are prevailing, the use of podium level buildings is not effective in increasing pedestrian thermal comfort. The research findings proved that the buildings with high podiums does not help to increase pedestrian comfort in Sri Lankan climatic conditions; since the wind flow in this context is not very strong as stated above. Further the placement of open areas proved to be critical as those could either increase or decrease the pedestrian thermal comfort due to the placement. Hence basically, urban planning strategies should be 'site specific' according to the observations of the research.

Based on the research findings the following design implications proposed are as follows;

- Pedestrian comfort at the selected area (LCZ2) is within the comfort zone at the current situation. But slight increase of temperature would make it uncomfortable. So, prevailing urban planning regulations should develop to consider wind manipulation strategies when converting these types of areas into LCZ1 areas in the near future.
- For the urban canyons which consist of adequate wind flow as in R1, mixture of deep canyons with regular canyons is the ideal setting as in the manipulated geometry_3 (S4). Even urban geometries are not suitable.
- H/W ratio of the canyon is critical in the manner of increasing wind funneling and channeling effects collaborated with Venturi effects; which helps to increase the average wind speeds through the canyon.

- Buildings with podiums does not helping to increase pedestrian comfort in Sri Lankan climatic conditions; because the downwashes are not so strong. Open areas should be planned at the places which consists of adequate wind flow as in R1, to activate courtyard effect for pedestrian thermal comfort.
- Direct wind disturbances to the streets should be avoided via urban planning and building aerodynamics. It can help to increase pedestrian thermal comfort at places such as R2.
- Places which are not getting adequate wind flow such as R2, should not have deep canyons. Avenue Canyons, as in the manipulated geometry_1 (S2) which are having H/W ratios less than 0.5, are more effective for those type of conditions in enhancing pedestrian thermal comfort.

Directions for Future Studies,

The present study puts forward a strong theoretical and empherical basis to the understanding of pedestrian comfort and the influence of urban geometry driven wind behavior on pedestrian comfort. Yet, due to the limited time period and available resources, scope of the research was carried within a limited framework in which one specific LCZ2 area which has the potential to be converted in to LCZ1 in the near future was considered. The Wind Tunnel Test was conducted only as a photographic study to understand the wind behavior at existing geometry whereas only 3 types of Manipulated geometries were used to simulate via ENVI-met. Also the research considered the overall geometry of urban canyons instead of focusing shadings and aerodynamics of individual buildings.

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