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WIND PATTERNS IN BUILT ENVIRONMENT

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Abstract :

Wind movement in environment is owing to the predominant, geographical wind in the region and its land form and land cover, natural or man-made, green or built environment. Wind experienced at a location can be described by two main attributes wind direction and wind velocity, apart from other factors viz. temperature, humidity, purity. The dense urban built environment interferes with natural wind affecting its natural flow, direction and velocity.

This research describes how the kind of development happening in cities influences and alters the local winds. The tall high-rise buildings, other man-made structures are obstacles to the wind movement whereas the wide roads acting as street canyons cause disruption of wind patterns.

This impact poses a challenge for the designers to identify the wind direction and configure the site layouts. If the phenomenon of how wind moves in certain built environments is known, buildings along with open spaces can be intentionally planned with a projected wind pattern to help in ventilation, especially in case of development of bigger parcels of land.

The paper aims to discuss change in wind flow and direction due to the form, height and orientation of buildings using 2 examples and basic wind principles. The study can be used to perceive how buildings affect the wind movement and to further adapt the composition of buildings to it.

***Index Terms* -** Wind Effects, Urban Environment, Wind Patterns, Natural Ventilation

1. INTRODUCTION

Air is the basic element of life; wind is the basic element while designing spaces for living. Wind speed and its direction play a significant role in natural ventilation and configuration of layout of buildings. Wind movement in the environment is owing to the predominant, geographical wind in the region. It is a further result of the land form and land cover there, whether green or built environment, contributing to the micro-climate of location.

Wind is the cognizable natural movement of the air in the atmosphere, in the form of an air current flowing from a particular direction. It is perceptible and measurable in terms of two main characteristics direction and velocity, apart from factors viz. temperature, density, humidity, purity.

All structures in the environment interfere with natural wind affecting its natural flow, direction and velocity. Natural wind pattern changes due to hills & dales, forests, farms and settlements in rural areas; whereas due to dense built environment happening in cities. The tall high-rise buildings and man-made structures are obstacles to wind movement. The wide roads become the street canyons causing disruption of wind patterns. This impact poses a challenge for the designers to identify wind direction and configure site layouts. If the phenomenon of how wind moves in certain built environments is understood, buildings along with open spaces can be intentionally planned with a projected wind pattern to help in ventilation, especially for development of bigger parcels of land.

1.1 Aim of the Research Paper

To discuss the change in wind flow and direction due to the form, height and orientation of buildings, especially in urban built environment.

1.2 Objective of the Research

To perceive how buildings affect the wind movement and to generalize on how the composition of buildings can be further adapted to it.

1.3 Scope and limitation

The research describes the wind pattern observed in urban built environment with respect to wind flow and direction only. Effect of other parameters of air viz. temperature, humidity, pressure, density, purity are not discussed or specified.

1.4 Research Methodology

The research is based on secondary data about air movement and wind from books, research and other digital sources. The literature and theories published are considered to demonstrate using 2 examples and analysis further.

2. PHYSICS OF AIR AND AERODYNAMICS WITH RESPECT TO AIR MOVEMENT AND WIND

Earth's atmosphere is the layer of gases, known as air, retained due to gravitational pull of earth, forming its atmosphere, surrounding all life and objects on earth. Aerodynamics is the way air moves around things and study of dynamics of gases in motion.

Air follows the laws of gases. It has weight. Warm air is lighter & tends to rise. Dry air is lighter & tends to rise. Air movement reduces density. Air movement or wind flow is due to pressure differential effect (wind effect) or temperature differential effect (temperature effect).

Air travels from higher density to lower density, higher pressure to lower pressure, lower temperature (cooler air) to higher temperature (warmer air), lower humidity (dry air) to higher humidity (humid air). Wind flows from a zone or direction which is cool or dry towards a zone or direction which is warm or humid. This movement of air sets the direction of flow of wind. The difference in density, pressure, temperature and humidity results in movement of air and accelerates it. Higher the differential, higher is the velocity of moving air causing wind.

Air is considered a fluid, as it may be made to flow or change its shape by the application of moderate pressure. Hence Computational Fluid Dynamics (CFD) applications are used to simulate wind flow around buildings. Air acts much like a fluid due to the way it flows around obstacles.

3. WIND, LAND-COVER AND WIND BREAKS

Wind movement on land is affected by the land-form, land-mass, land-cover and assigned land-use over it. Different regions exist with natural land-covers and develop with man-made land-use. Natural land-cover is the indigenous soil, water, vegetation forms like grasses, farms, shrubbery, trees in the region; while man-made land cover includes the buildings, roads, infrastructure, open spaces, green areas, water bodies by virtue of development of centers. All structures interfere with natural wind flowing over the region, affecting its velocity and direction. Wind gets deflected from its original path and slowed down by these structures which act as obstacles or wind breaks.

3.1 *Luv* and *Lee*

These are names of sides of the object or reference point in relation to wind, used by sailors since 17th century. *Luv* (German, pronounced as "luff") is the windward side facing the wind, or the direction upwind from the point of reference and facing the direction from which the wind is coming. *Lee* (German) is the leeward side facing away from the wind, or the direction downwind from the point of reference and facing the direction toward which the wind is blowing. Trees and buildings are standing against the wind. Positive pressure is created on the side that faces the wind (windward side) whereas suction regions or negative pressure is formed on the opposite side (leeward side) and on the side walls. Hence, if openings are created on all faces, it creates air movement from positive to negative pressure facilitating ventilation of indoor spaces.

3.2 Wind Shadow

Due to wind being blocked by an obstruction such as a land-form, building or trees, a windless area of quiet air or low-winds is created on leeward side (Figure 1). This wind shadow area extends on downwind-side of the building for a length of 3-4 times its size, depending on its roof profile and dimensions (Figure 2a, 2b, 2c). Due to negative pressure zone formed, this zone may experience reverse downward currents or breeze with turbulence.

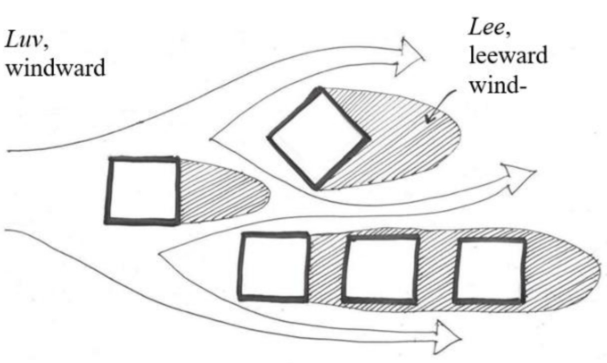


Fig.1: Luv, Lee, Wind Shadow

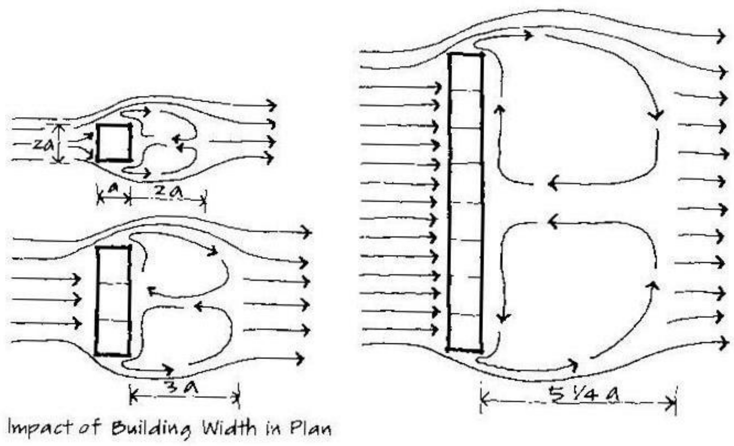
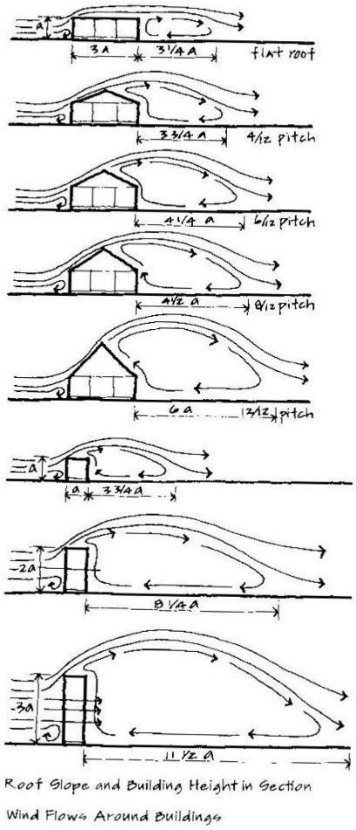


Fig.2a: Building width and Wind Shadow zone (Brown, DeKay, 2001)



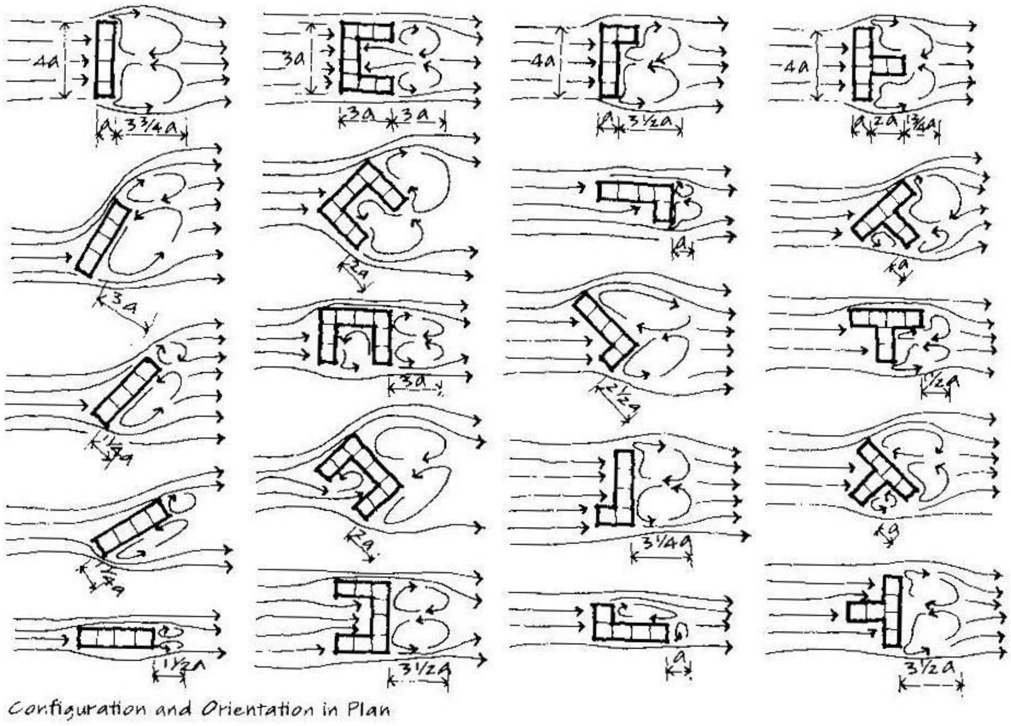


Fig.2b: Building height and Wind shadow zone
(Brown, DeKay, 2001)

Fig.2c: Building configuration and Wind shadow zone
(Brown, DeKay, 2001)

3.3 Wind in cities

When winds travel in rural areas, they come across fewer obstacles due to lesser man-made structures. Hence, they flow more smoothly with a constant wind speed and direction. Whereas when winds make their way into a city, they get obstructed by construction and built infrastructures, deflected off their surfaces and get augmented at times. Hence, there are differences in wind flowing in the city as against the countryside with respect to movement patterns, direction and speed. Urban areas are windier than rural counterparts. This is called the "Urban Wind Island Effect". The effect is noticeable in early morning and late afternoon, around the sunrise and sunset times when air temperature is transitional. Urban winds are difficult to capture in observations and for simulation modelling, due to complexity of development, neighborhood geometry, configurations and ever-changing climate. The studies are often focused on individual buildings or a complex, mostly not considering landscape elements that play a vital role in the effect. Incorporating Urban Wind Island concept for the city helps to understand wind patterns with clarity, use these patterns while testing efficiency of ventilation for urban, architectural design process, study how a proposed structure or complex impacts wind flows in the surrounding area, create more accurate CFD models for urban winds and for the purpose of quantifying urban wind energy potential, air pollution, safety of installation of equipment, wind load impact, etc. (Droste, Steeneveld, 2017).

4. WIND PATTERNS IN URBAN ENVIRONMENT

Urban development which is a result of urbanization of a location comprises of man-made structures and construction including buildings, roads, green areas and other infrastructure. When a building like object comes in the way of wind, a high pressure zone of increased velocity is created on the windward side and low pressure zone of low velocity on the leeward side. As a result of motion inertia, it continues to move in the same direction like a fluid, gets deflected but not stopped. Buildings obstruct and divert the incident wind in different directions creating a number of effects depending on their height, the profile facing the wind and the speed of wind and angle at which the wind flows into them. (Rheologic GmbH, 2021)

4.1 Upward deflection effect:

When wind travels with a speed and force onto a vertical structure, it blocks the flow of wind splitting it into directions with least resistance, partly vertical and partly on sides of the building. It is the effect that diverts the wind upward after getting obstructed causing no change at ground level (Figure 3).

4.2 Side-ways-deflection effect

When the windward building face is (convex) circular, more horizontal less vertical or wind speed is less, deflection of wind is more side-ways, without affecting air at ground level (Figure 3).

4.3 Downward-deflection or Down-draught effect or Downwash

When stronger winds run into tall buildings at greater heights, wind is deflected downward as well, flowing towards the streets and open spaces causing turbulence and then in different directions (Figure 3).

4.4 Downwind eddy effect

After getting deflected vertically and side-ways by the wind-ward side of the buildings, the wind bounces up to longer distances downwind creating a quiet wind-shadow zone. Eddies are reverse currents created due to pressure difference causing light breeze or turbulence (Figure 3).

4.5 Counter-current effect

When wind moves in opposite direction to its flow, it causes counter-currents. These light gentle winds or irregular draughts may be caused by reverse deflection of wind by obstacles or by reverse movement of wind in the negative or no pressure zones (Figure 3).

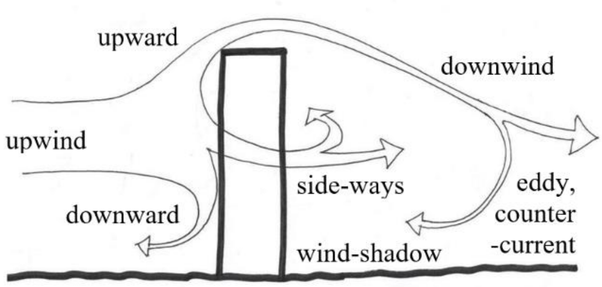


Fig.3: Wind Deflection Effects

4.6 Venturi effect

The speed of air increases when it flows through a narrower space from a wider space, without changing its rate of flow and volume. While flowing into urban environments, wind gets constricted by line of buildings, increasing its speed significantly. This phenomenon explaining why wind speeds vary in city areas is called Venturi effect, found by Italian physicist Giovanni Venturi in 1797 (Figure 4).

4.7 Wind tunnel effect

The smaller space in between two lines of buildings causes low air pressure. Wind moves faster in a circling motion while passing through it, having deflected by buildings on either side of the narrow space. Same effect is also seen when wind travels through long corridor of rooms inside a building (Figure 5).

4.8 Street canyon effect

Urban environment is a layout of buildings and roads, with buildings on both sides of long roads and long open spaces between the buildings. These spaces in between the buildings resemble street canyons. Wind accelerates while moving through this restricted space. If wind is perpendicular to it, it results into pockets of turbulence in between buildings. If wind is at an angle, then both effects are observed. Street canyon effect is dependent on dimensions and proportions of the street canyon (Figure 5).

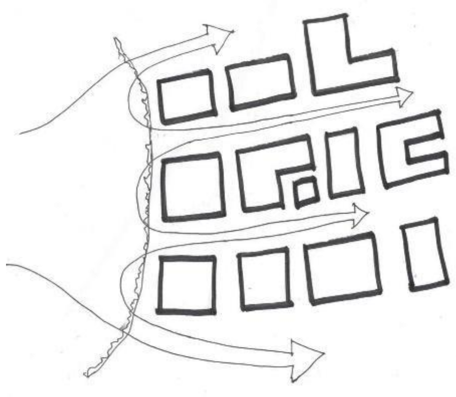


Fig.4: Venturi Effect

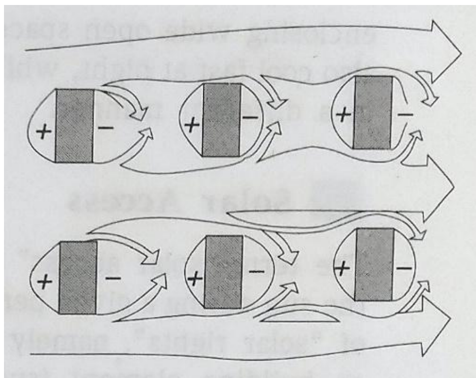


Figure 5: Street Canyon, Wind Tunnel (Krishnan *et al.*, 2001)

4.9 Height or Speed effect

Wind speed increases with increasing height above ground. Flow near ground surface is interfered by obstacles like trees and buildings reducing wind speed and creating wind patterns with random vertical and horizontal velocity components. This is referred to as Wind Shear. Surface roughness of terrain and development decelerates the wind. Higher altitudes offer less surface friction. Hence, wind speed increases with increasing height above ground (TeamCivil, 2017). The rate wind speed increases with unit height is called Wind Gradient, which determines Wind Speed Profile of a region (Aiyer, 2021).

5. WIND PATTERNS AROUND BUILDINGS

Wind interacts with the built form in complex ways creating different wind flow patterns. "Direct Winds" are received and deflected by the upwind side of buildings. Light circular winds, eddies or counter-currents are experienced in the downwind low pressure zones. These can be termed as "indirect Winds". Figure 2a, 2b and 2c show the impact of building dimensions and profiles. Depth of wind-shadow area increases as the height and width of building increases. Similar patterns are found when wind interacts with trees. It splits around the cluster or line of trees, flowing over the ridge creating wind-shadow area behind depending on the height of trees. (Azizi, Javanmardi, 2017)

5.1 Wind patterns of a neighborhood,

Example-1: A residential neighborhood of size 360 meter x 348 meter (ground slope towards south-west corner 27 feet i.e. 8 meter down) in Vimannagar area of Pune city, Maharashtra (Figure 7) is considered for evaluation of wind flow through the buildings using basic principles of direct and indirect winds. West is used as predominant wind direction with respect to Pune weather data of past five years (Figure 6).

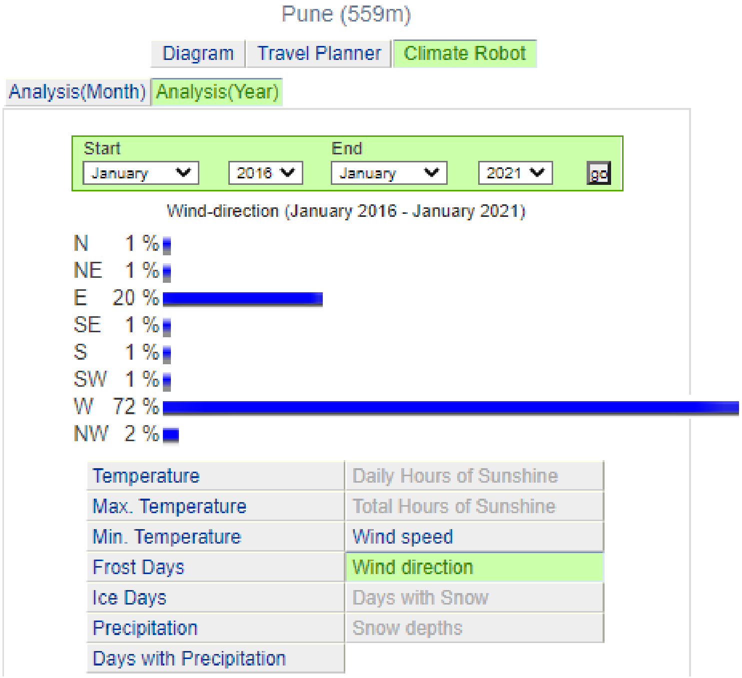


Fig.6: Pune Wind Direction for past 5 years (WeatherOnline, 2021)

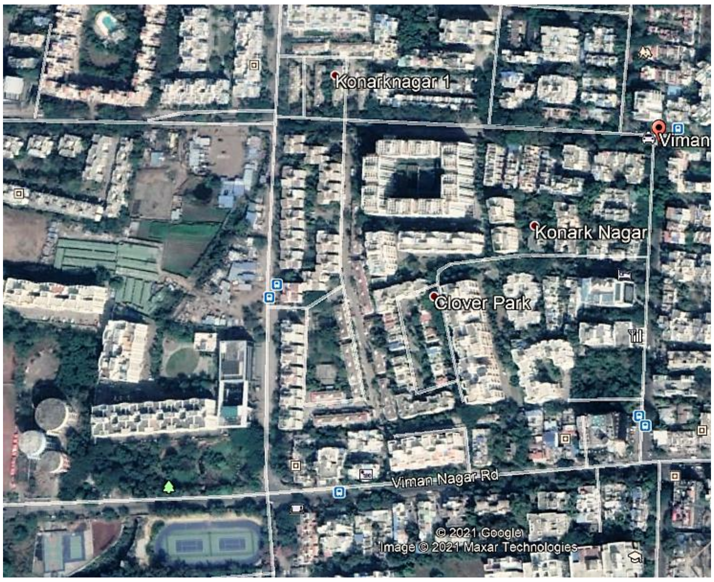


Fig.7: Satellite image of Vimannagar neighborhood, Pune (Google, 2021, Maxar Technologies, 2021)

5.2 Analysis of Example-1

Buildings facing the open space on the West i.e. the windward side receive strong natural winds. Due to dense construction and height of buildings (Parking +7 floors) around 24 meters, wind slows down while entering the neighborhood. Most of the buildings fall in the wind shadow zone and rely on indirect winds or eddies. Change in wind direction to East for some part of the year reverses the air flow dynamics and soothes the otherwise downwind side. Presence of trees though cools the environment on hot summer days, creates a difficult situation for lower floors of the buildings to get any direct or indirect wind. The best of the windy experience is above the tree height, approximately 10-12 meters i.e. 3 floors above ground (Figure 8).

Fig.8: Wind and Wind shadow analysis of Vimannagar neighborhood, Pune using thumb rules, above 12m tree height
(OpenStreetMap, 2021 for template map image)

6. EFFICIENCY IN NATURAL VENTILATION

Example-2: 3D model in Computer-aided Design (CAD) software by Sugiona Sugiona, University of Brawijaya (UB), Malang, Indonesia was simulated using CFD software for some locations of UB campus to measure wind speed at 1.7 people height. Research was conducted concerning towards quality of air, comfort and safety of pedestrians in the university area. The measurements from this experiment are considered as an example to further understand the efficiency in natural ventilation.

Wind speed required for comfort conditions, indoor or outdoor, is 1.5 m/s (i.e. 5.4 km/h) to 2.5 m/s (i.e. 9 km/h) with reference to Beaufort wind force scale and standards of ventilation. With efficient opening design, indoor wind speed can be expected to be 40-45% of that outdoors (Bureau of Indian Standards, 1978). Hence, to achieve indoor wind speed 1.5 m/s, corresponding outdoor wind speed requirement is 3.33-3.75 m/s for comfort conditions. To achieve minimum indoor wind speed 0.5 m/s, outdoor wind needs to be at 1.11-1.25 m/s accordingly. The observed outdoor wind speed in the CFD model of UB layout is used for analysis of efficiency in natural ventilation.

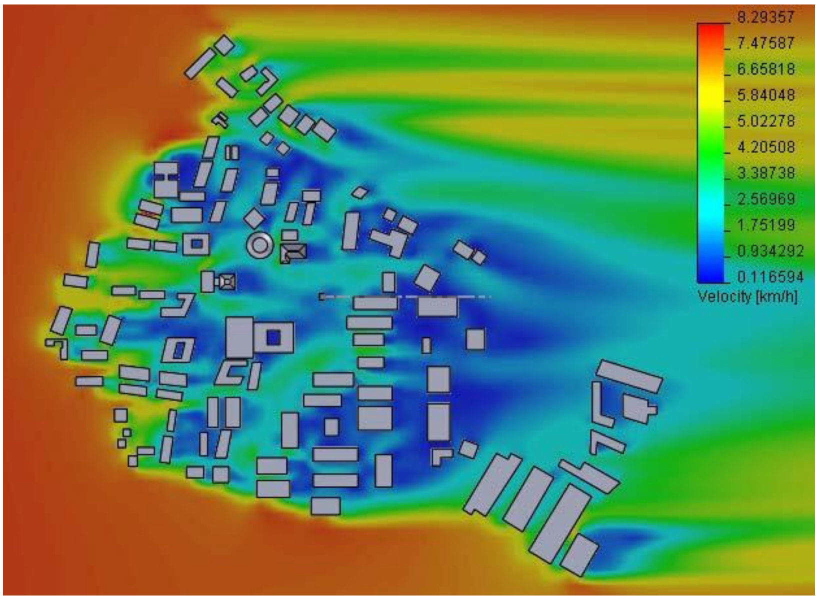


Fig.9: CFD simulation model at 1.7m for wind speed
(Sugiono, 2014, ResearchGate GmbH, 2014)

6.1 Analysis of Example-2

Considering the university layout example and its CFD model, it is observed that with 8.29 km/h i.e. 2.30 m/s natural wind speed, part of the university in wind shadow (cyan-to-blue) does not experience even minimum air movement. Most of the university campus in wind shadow zone (green-to-cyan-blue) receives slower winds, not efficient in effecting into natural indoor ventilation. As the CFD model is taken at 1.7 meter height, natural ventilation of interior spaces at ground floor is at minimum air movement level for the front upwind buildings only. Natural ventilation of ground-level exterior upwind spaces of all buildings is at comfort condition (Table 1).

Wind speed data of 3D CAD model in CFD software			
of University campus layout			
by Sugiona Sugiona, UB, Malang, Indonesia			
Appraisal of outdoor wind speed for natural ventilation			
Outdoor Wind speed at 1.7m height, CFD experiment measurements		Efficiency for indoor ventilation comfort: >3.33m/s, minimum: >1.11m/s	Efficiency for outdoor ventilation comfort: >1.5m/s, minimum: >0.5m/s
(km/h)	*(m/s)*		
8.29357	2.30	□	□
7.47587	2.08	□	□
6.65818	1.85	□	□
5.84048	1.62	□	□
5.02278	1.40	□	□
4.20508	1.17	□	□
3.38738	0.94	□	□
2.56969	0.71	□	□
1.75199	0.49	□	□
0.934292	0.26	□	□
0.116594	0.03	□	□

Table.1: Ventilation Efficiency of CFD model

7. CONCLUSION

Natural wind for a location differs with the micro-climatic factors including terrain and kind of development. Wind interacts with obstructive structures: land-form, trees and buildings affecting its flow, direction and velocity. Urban environment with dense tall constructions slows down the wind, deflects it in different directions to create wind patterns and puts subsequent land in wind shadow zone. While designing building layouts, especially in city areas, understanding patterns in wind movement is essential so that maximum number of buildings receive direct winds. Indirect winds or eddies in wind shadow area are not reliable but can be an advantage. Since indoor air movement can be achieved upto 40-45% of the outdoor wind velocity using opening design strategies, orienting important activities to windward side and unimportant activities to leeward side can be followed for configuration of layout and building plans. Trees and tall plantation need to be strategically added or incorporated in layouts, as trees also slow down the wind and create wind-shadow areas depending on their height. Wind patterns in urban environment can be determined precisely to a detailed level if wind direction is studied along with other variable wind speed (and the height effect), to understand its cumulative influence, using the computational simulation models.

8. ACKNOWLEDGEMENTS

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