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Outdoor Ventilation and Ground Coverage: Exploring a Climate Centric Approach to Building Byelaws for Multi Storied Apartments in Bhubaneswar

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Outdoor Ventilation and Ground Coverage: Exploring a Climate Centric Approach to Building Byelaws for Multi Storied Apartments in Bhubaneswar

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Bhubaneswar with a warm and humid climate and with humidity much higher than the comfort level requires an enhanced natural ventilation to achieve long term quality of life. The building code which regulates the fabric of the city at present follows a standardized set of regulations governed by National Building Code of India and is developed without giving much consideration to climate. Ground coverage is an important parameter which regulates the footprint of the blocks and allows natural ventilation to buildings as well to outdoor. At present, Bhubaneswar does not prescribe a ground coverage for its apartments and completely dependent on FAR control. As a result, the developments consider quite high ground coverage in certain areas. This particular research focusses on analyzing the current situation of multi storied apartments and proposes a few climate centric recommendations for the byelaw. To examine the situation and arrive at a strategy, a simulation study has been carried out by altering the ground coverage and building orientation of a multistoried apartment consisting of five residential blocks to analyze the effect of natural ventilation. The study inferred that, building layout and orientation in relation to wind direction plays an important role for natural ventilation in the outdoors. A climate centric byelaw ideally should consider both while formulating its building code.

Keywords: Multistoried apartments, outdoor ventilation, ground coverage.

Introduction

Because of anthropogenic activities, cities are undergoing a number of environmental problems; one among them is urban overheating caused by urban heat island (UHI). An important reason for UHI is changing morphology of the city with high density developments which absorbs a lot of solar radiation and alters the air flow (Oke et al. 1987; Santamouris 2015). The developments or urban forms of a city are the result of combination of building arrangements, building's height, their distances among themselves, and their built space (Azizi et al.2017). Urban forms are site specific and often results in uncomfortable urban environments, which in turn increases building energy demand (Quan et al. 2016; Abdallah 2015). However careful consideration of urban form can improve the environment, increase natural ventilation which in turn not only lowers energy

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demand, alongside improves the health and wellbeing of urban residences and helps to achieve long term quality of life (Ng 2009).

Considerations for factors like wind flow can improve the microclimate of the urban areas mostly in warm and humid climate. Wind speed has widely been reported to have lessened the intensity of UHI effect in urban areas. The cooling effect of wind helps to mitigate the adverse effects on the microclimate and human thermal comfort. In tropical regions such as Singapore, a wind velocity of 1–1.5 m/s creates cooling effect which is equivalent to a 2 °C drop in temperature (Rajagopalan et al.2014). Literatures revealed that there are seven critical morphological variables that determine natural outdoor ventilation efficiency within a said precinct area or development. They are 'building orientation', 'canyon geometry', 'building type', 'building coverage ratio', 'height variations', 'gaps between buildings' and 'staggering' (Lee et al. 2015).

A number of researches are done on the morphological variables and their influence on outdoor ventilation. Canyon geometry, as formulated by Oke provided a major kick start to the importance of urban morphology elements on outdoor ventilation (Oke 1988). Later, several researchers experimented with various canyon geometries to strengthen the importance of aspect ratio on UHI (Giannopoulou et al. 2010; Andreou 2013). Along with street canyon geometries, the wind direction or orientation of buildings also given enough emphasis to introduce more wind to urban streets thus improving the ventilation process (Wai et al. 2020; Bady et al. 2011). By varying the wind angle, the inflow of wind and its speed also varies (Erell et al.2011; Leite et al. 2011). A study on Housing and Development Board residential estate by Lee for different height variations of buildings explained the importance of external wind flow within the precinct for both pedestrian and mid height levels since wind flow is affected differently by the height variation (Lee et al.2015).

Morphological variables suggested that while building orientation, building type and staggering are design interventions; building coverage ratio, aspect ratio, distance between buildings and height variations are the result of building bye laws. Composing urban codes and regulations is a means of achieving goals of sustainable development and ensure the formation on sustainable residency (Salehi et al. 2007). Floor area ratio (FAR); an important aspect of any development in today's world usually controls building coverage ratio and building height variations. A continuous and consistent streetscape as suggested by Oke for canyon geometry is difficult to find in emerging Asian cities since the developments are now governed by FAR (Yang et al. 2013). A three-dimensional approach in form of FAR, building height and density need to be considered while understanding the pattern of wind.

Buildings can be used to protect the site from undesired wind or to induce wind movement within it depending on the prevailing climatic conditions (Koenigsberger 1975). However, the building codes regulate these spaces through its standardized guidelines provided by National Building Code of India (NBC,2005). Floor area ratio (FAR) centric bye laws; a set of rules framed by the state government, are imposed on development work of a city to ensure control on planning, design and construction of buildings to achieve safety and better quality of life for the residents. Climate a significant factor for achieving comfort is often ignored or neglected while deciding the building development regulation. Most of these regulations are observed to be repetitive for different towns without much consideration of the local weather pattern (Kumar 2017). In addition, the wind direction and wind speed consideration are completely overlooked while framing the byelaws.

The study examines the airflow pattern in multistoried apartments by means of computer simulation and tries to analyze the effectiveness of ground coverage on ventilation by using the prevalent wind directions of Bhubaneswar. Since Bhubaneswar does not prescribe a fixed ground coverage and completely dependent on FAR, this performance-based approach hopes to contribute to the importance of ground coverage in a warm and humid climate. The study subsequently indicates a path for deriving regulations for other climates; thus, creating a sustainable growth for the city.

Literature Study on Ground Coverage

Several researches are done on ground coverage and its influence on natural ventilation. This literature tries to focus only on certain recent studies. Peng et al. conducted a simulation study generating 101 non repetitive models of varying ground coverage. The ground coverage varied between 11% to 77% to analyze the effect of ventilation and pollutant dispersion in the outdoor. Results show that, local ventilation performance is not directly related ground coverage, rather it is dependent on building arrangement. As ground coverage increases, the ventilation at the central area does not necessarily keep decreasing. Some form with low ground coverage has poor ventilation whereas some form with higher ground coverage has better ventilation (Peng et al. 2019).

Wang et al. investigated the ventilation performance for 48 scenarios. The air flow at the pedestrian level is measured at the level of 2m from ground level. The study inferred that, ground coverage scenario is the most important parameter for good ventilation, however effect of other factors such as building height or aspect ratios should not be ignored (Wang et al.2017). Guo et al. analyzed the morphology of a high-density downtown, Dalian city on its urban ventilation performance. The study inferred that urban ventilation is largely dependent on the layout of the building form. By reducing the density of a study area but maintaining the same FAR improved the ventilation of the area to a larger extent (Guo at al. 2017). Another study on Bangkok inferred that, high-rise high-density areas have better ventilation potential than low-rise low-density areas (Srifuengfung et al.2013). However, Yahia et al. in his study for Dar es Salaam having warm and humid climate inferred that, closely spaced buildings have negative impact on the ventilation (Yahia et al. 2018). The average wind speed in high density, high rise areas are less in comparison to less dense areas. Research also derived a reference urban model for a residential area in Shanghai and examined its ventilation efficiency at pedestrian level. The results show that, low building coverage ratio leads to better ventilation (Hu et al. 2013).

The summertime outdoor ventilation potential for high rise housing of Shanghai is studied by using empirical data from an extensive field measurement. A total of 10 residential high-rise building sites were chosen for the study. At the site level, the building FAR and Building coverage ratio appeared to be negatively related with wind velocity. Open spaces covered with grass and minimum albedo surface pavement favoring appropriate wind direction suggested for better ventilation potential in ground level. It is also found out that there are several other factors which also have influenced the final outcome of the study and hence the findings are to be studied in a rather controlled environment (Yang et al.2013).

Not only natural ventilation, several studies also highlighted the influence of ground coverage on solar protection. Wong et al. assessed various morphologies around a particular building in Singapore and their impact on temperature and energy consumption of that building. In the experiment they studied the influence of surrounding building height, surrounding building density and presence of vegetation on the energy consumption of the building. They increased the Ground coverage by increasing the density of the buildings around the main building. It is observed from the experiment that with the increase in ground coverage the temperature decreased up to 0.6 K during the day but increased during the night. Higher surrounding buildings also tend to lower daytime temperature but increase nocturnal UHI. In a similar way, combined effect of maximum height and maximum density also increased the nocturnal UHI (Wong et al. 2010).

Cheng et al. studied solar exposure in different urban forms with varying density. They admitted that recent planning guidelines are promoting higher density through compact urban form without examining thermal effect of compactness. They analyzed solar behavior in eighteen generic model of urban development; each comprises different combinations of building-form and density. These eighteen models are generated by varying Floor Area ratios and site coverage. Two types of site coverage are considered for study. They are 9% for low coverage development, and 36% for high coverage development. It is found out from the study that; density affects solar radiation potential differently based on building arrangements and building height (Cheng et al. 2006).

By looking at the literatures it is deduced that, a greater number of the studies focused on study models than real life situations. The study models use repetitive standardized urban blocks. As a result, the real-life implementation is neglected. The aim of the study is to simulate urban blocks considering real life situations. In addition, the building byelaws is specifically emphasized due to its positive relationship with urban morphology. An individual parcel level strategy is adopted which can be easily integrated with building byelaws and practically implemented to achieve sustainable urban form.

Climate of Bhubaneswar

Bhubaneswar's geographic location is defined by 20.27° North Latitude and 85.84° East Longitude which is under a warm humid tropical climate zone (Fig 1). The author explained the warm humid climate zone of India, which is bordered by Bay of Bengal, Indian Ocean and Arabian sea (Dash & Chakraborty 2018). The climate is quite similar to other cities such as Singapore, Hawai, Malaysia etc. in terms of temperature and humidity. Month of November, December and January are considered the coldest months.

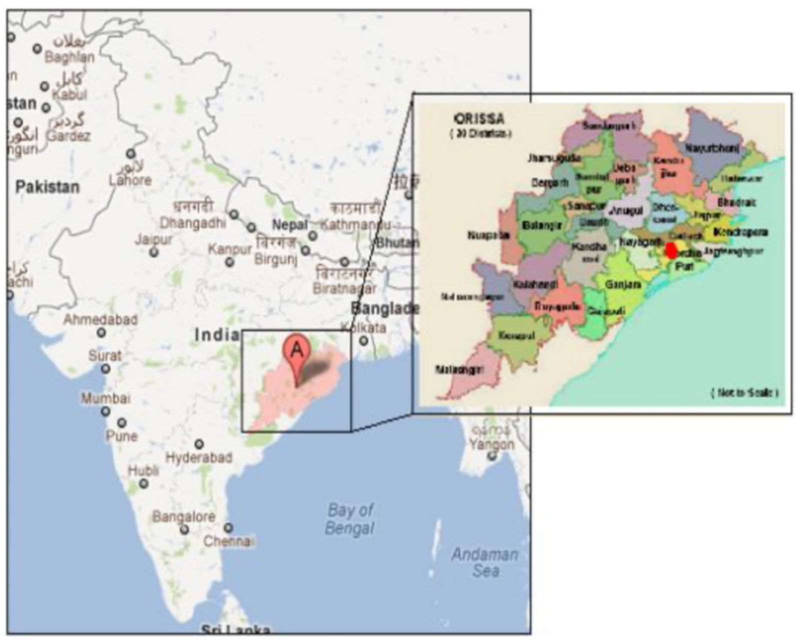


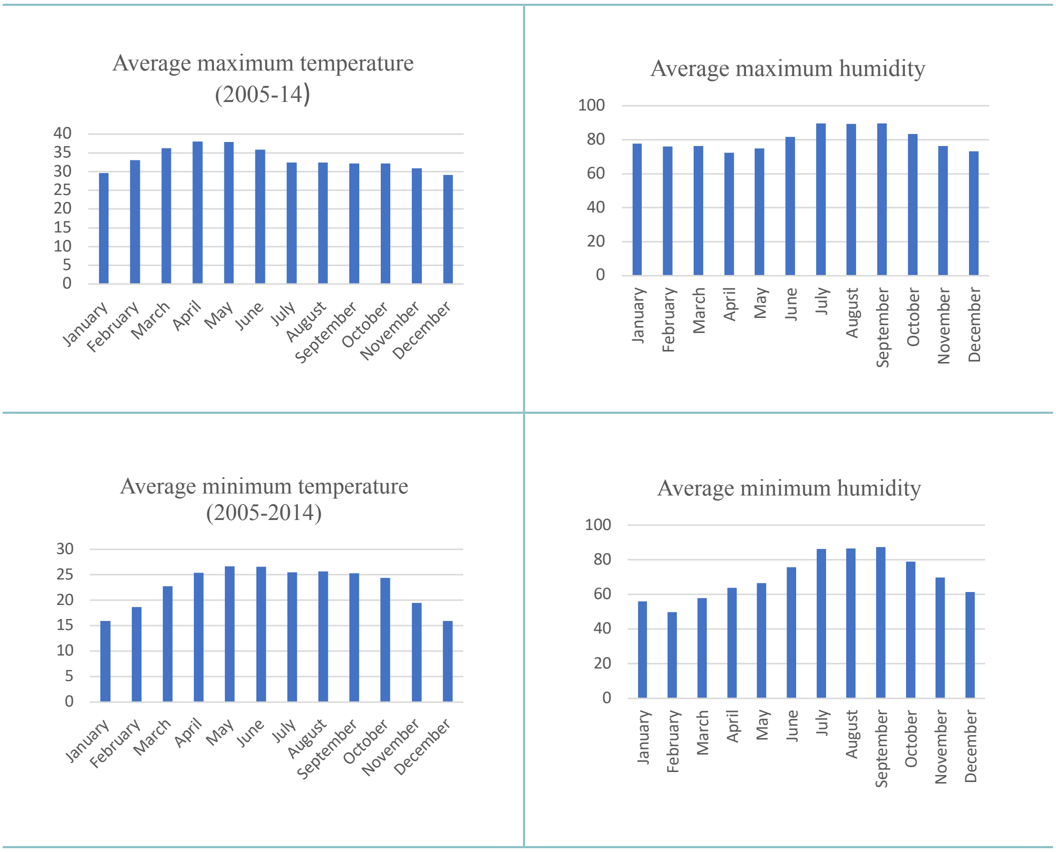
Fig. 1

Location of Bhubaneswar

Bhubaneswar's climate can be characterized by high temperature and high humidity which is above 80% during most part of the year. Unfortunately, both of these characteristics are the reason of thermal discomfort. During two third of the year, the average high temperature exceeds 30 °C. Moreover, in the month of March, April and May the maximum temperature exceed 35 °C. Table 1 explains the average temperature and humidity of Bhubaneswar from 2005-2014.

Table 1

Temperature and humidity measurement

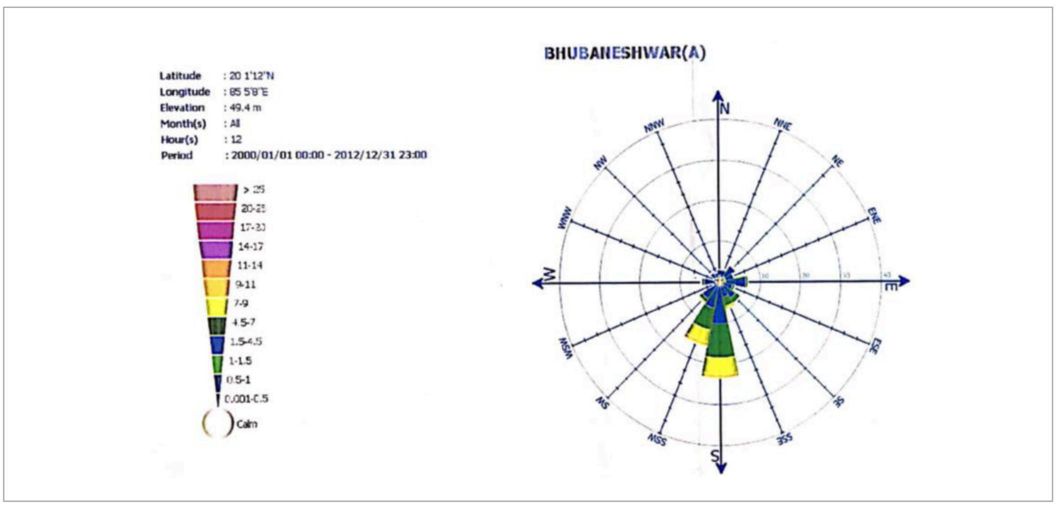


Source: Meteorological department.

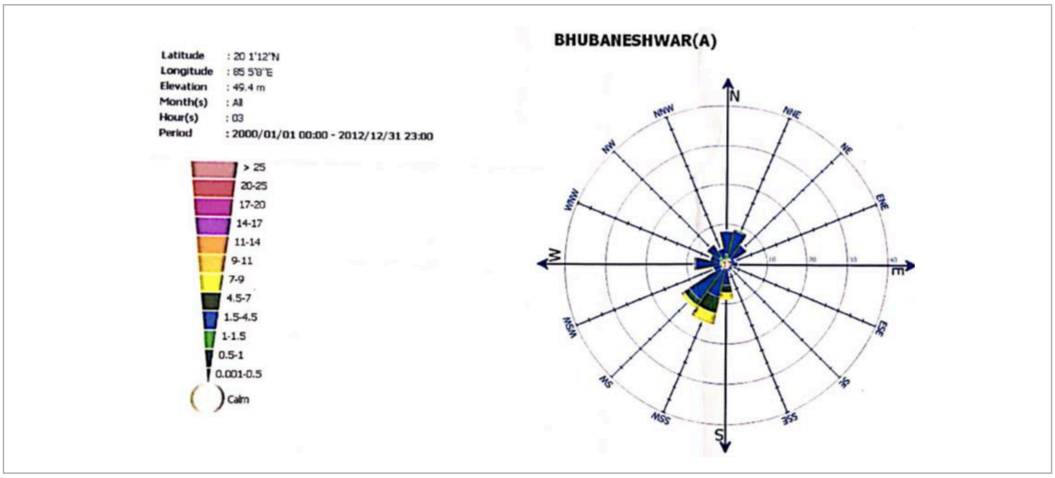
Wind is desirable in this climate as it could cause sensible cooling to the body. The main design criteria of warm and humid region could be to reduce heat gain by providing shading and promote heat loss by maximizing ventilation. Prevailing wind direction for Bhubaneswar is from South and South West (Fig. 2 & 3). In the month of April – May which is hottest period of the year observes a high wind speed above 5m/sec (Fig. 4)

Fig. 2

Wind rose of 12 years at 12 pm



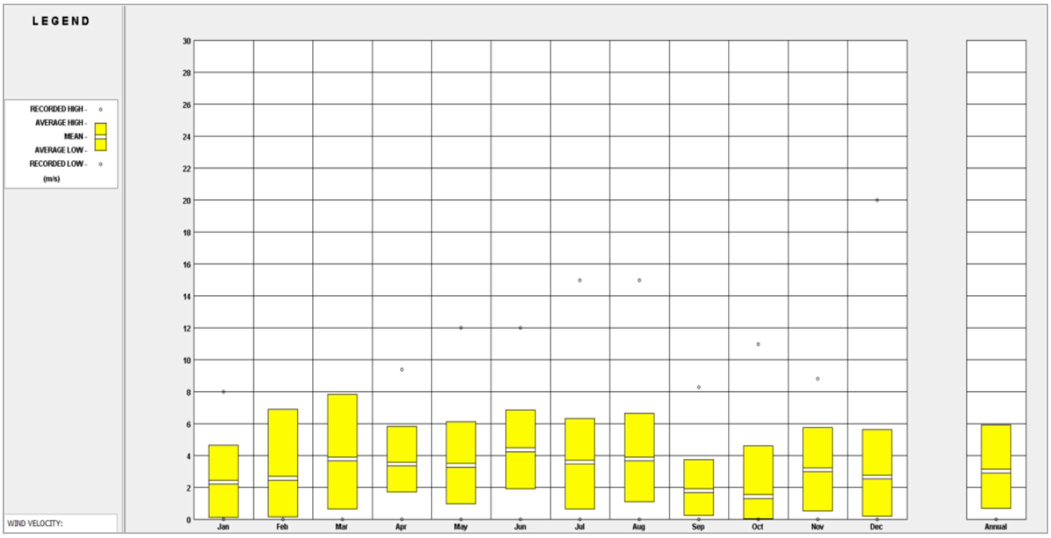
Source : Meteorological department



Source: Meteorological department.

Fig. 3

Wind rose of 12 years at 3 pm



Source: Climatic Consultant.

Fig. 4

Average wind speed of Bhubaneswar throughout the year

However, this wind is not used for effective ventilation due to the unplanned nature of the building development. As a result, the internal heat as well as the heat gained from solar exposure are trapped inside and make the indoor and outdoor warmer. If this wind can be harnessed properly, it can definitely reduce the thermal discomfort in a larger extent.

Building Codes of Multi Storied Apartment, Bhubaneswar

The byelaw of Bhubaneswar concentrates on four parameters; Ground coverage, FAR, setbacks and open space reservation. While the front, rear and side setbacks are dependent on the building height, the FAR control is based on the approach road width. There are three levels of modification on building code proposed since 2001.2001 byelaw observed to have restrictions on plot sizes and ground coverage for multi storied apartments. There were also enough considerations for plantations and open space reservations. 20% of the plot area planned to have plantation to maintain the green image of the city (Table 2). However, gradually the ground coverage lost its prominence and a FAR driven approach came to existence. The FAR driven approach definitely provides more flexibility to the builders but does not describe its effectiveness for natural ventilation. The author compared three climatic zones and their byelaws for Indian cities in another article which provided the need for a climate centric approach to regulations (Dash & Chakraborty 2018).

Table 2

Parameters of byelaw of Bhubaneswar

Zoning Regulations	2001	2008	2017
Min Road Width	12m	9m	12m
Plot size	1000 sqm	500sqm	2000sqm
	2000 sqm		
	3000 sqm		
Ground Coverage	50%	Not mentioned	Not mentioned
FAR	2.00	Based on Road width	Based on Road, Maximum FAR reduced from 2.75 to 2.00
Front setback	6m	Based on building height	Same as 2008
Side and rear setback	Based on depth or width of site, goes to a maximum of 3m.	Based on building height	Same as 2008
Open space reservations	20%	Not mentioned	1 tree for 80 sqm of land

Source: Bhubaneswar development authority

Methodology

The aim of the research is to analyze the influence of ground coverage on the outdoor ventilation of multi storied group housing developments. Bhubaneswar has been considered as the study area since it has a warm and humid climate and is in the process of rapid urbanization leading to chaotic developments. In addition, Bhubaneswar also does not prescribe any fixed ground coverage criteria. This study aims to develop a climate influenced building regulation which will ultimately enhance the quality of life of residents. To evaluate the present situation of the developments and to arrive at a solution, the following steps are been adopted.

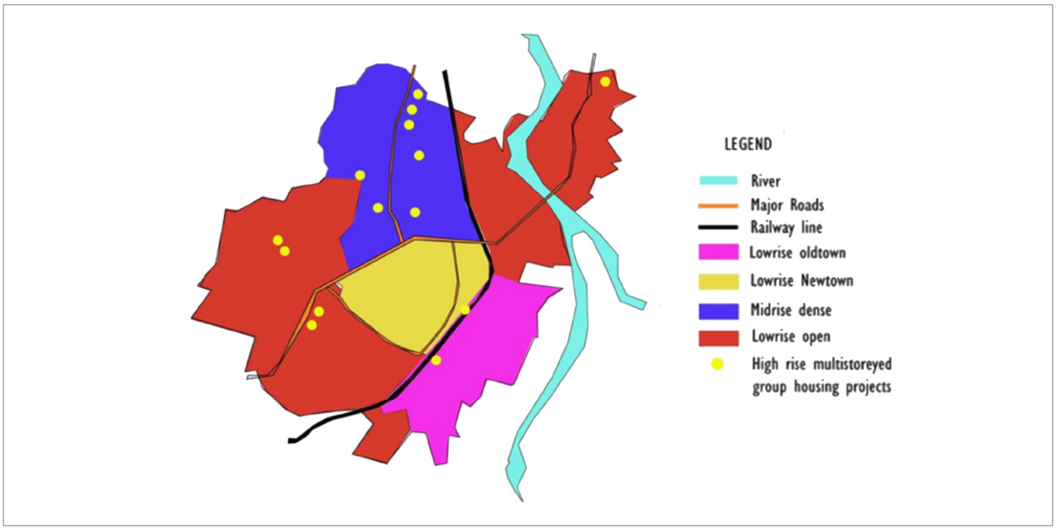
- Identifying multi storied apartments
- Identifying the typology of apartments
- Selection of base case and creation of hypothetical cases
- Deciding the tools and techniques
- Analysis using simulation
- Results and discussions
- Conclusions and Recommendations

Identifying multi storied apartments

Multi storied apartments are a recent phenomenon in Bhubaneswar. During the visual survey, 14 multistoried apartments are observed in the Bhubaneswar municipality jurisdiction. Multi storied apartments are more than 5 storey high and having more than a single block. Most of them located in the outskirts, in the Bhubaneswar development authority jurisdiction (BDA). Though the developments are clustered towards the northern and western side, few apartments are also observed in the center of the city. BDA jurisdiction is divided into three typical zones. The northern side is denser with mid-rise apartments and other buildings, the center part of the city termed as new town is designed by Otto Konigsberger is relatively low rise and western side is relatively less dense and organic in nature (Fig. 5).

Identifying the typology of apartments

By examining the typology of the apartments, it is found out that there are three types of apartment blocks prevalent in Bhubaneswar; linear blocks, combined towers and isolated towers (Table 3). Developments with isolated towers need to have setbacks around all its sides and hence observed to have the least ground coverage. Dense areas tend to have developments with linear blocks or connected blocks perhaps because of the non-availability of larger parcels. As a result, the ground coverage of those developments is much higher, many a times crossing 45%. A detail description of the apartment typologies is mentioned in Table 4 and 5.



Source: author.

Fig. 5

Location of multi storied apartments

Table 3

Typology of high-rise apartments

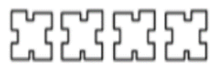
Typical Building block typology			
Typology	Linear Blocks	Combined Towers	Isolated towers
No of each type	03	08	03

Table 4

Satellite images of high-rise apartments with site extent more than 10 acres

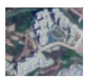
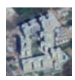
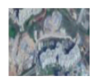
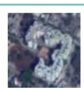
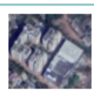
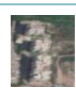
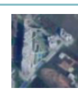
Satellite Image of the Built Form						
Foot Print of the Layout						
Name of the Apartment	Mani Thirumala	Royal Lagoon	Vipul Garden	Cosmopolis	Tata Ariana	Z1
Location	Midrise Dense (outskirts)	Mid rise Dense (Outskirts)	Low rise open	Low rise open	Low rise open	Midrise Dense (outskirts)
Site Extent (Acres)	12	12	10	09	12	30
Ground Coverage	30	30	20	25	25	25

Table 5

Satellite images of high-rise apartments with site extent less than 10 acres

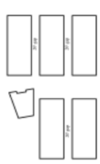
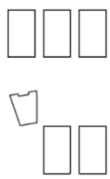
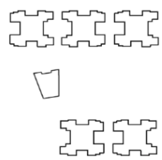
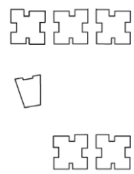
Satellite Image of the Built Form								
Foot Print of the Layout								
Name of the Apartment	Chandrama	Utkal Residency	West End	Club Town	Norther Heights	DN Oxy Park	Utkal Heights	Gangothri
Location	Low rise New town	Low rise new town	Mid rise dense	Mid rise dense	Mid rise dense	Low rise open	Low rise open	Mid rise dense
Site Extent (Acres)	4.4	4	2.4	2.6	3.5	4.1	5	5.3
Ground Coverage	44	46	46	46	40	25	18	45

Selection of base case

Club town apartment is chosen as the base case for the analysis due to its simpler form and higher ground coverage. Four hypothetical scenarios are created with the help of simulation software. Scenario 1 & 2 has a linear form placed in grid iron fashion. In scenario 3&4, tower forms are used for the study. The purpose of the study is to examine the typology and ground coverage appropriate for a warm and humid climate. Three types of housing blocks were considered for the study. Linear blocks with 6 units of size 17.6 mx47 m (58'x 154'), linear blocks with 4 units of size 17.6 mx31.4 m (58'x103') and tower blocks of 28.3 mx30.5 m(93'x100'), 23m x 24m (76'x79') all rising to 20 stories. The highest height achieved by high rise apartments is 20 story in Bhubaneswar. Hence the same height is chosen as the benchmark to examine the condition in the extreme scenarios. Size of the blocks which are prevalent in most of the cases are used for the study (Table 6).

Table 6

Hypothetical cases for simulation

	Case 1		Case 2	
Arrangement	(Side by side)	(Side by side)	(Side by side)	(Side by side)
Typology	Linear block with 6 dwelling units	Linear Block with 4 dwelling units	Tower block with 6 dwelling units	Tower block with 4 dwelling units
Layout				
Ground Coverage	40%	30%	35%	25%
Building block size	58'x154'	58'x103'	93'x100'	76'x79'

Deciding the tools and techniques

The most commonly used techniques to study wind flow in and around buildings are-wind tunnel testing and CFD (Sreshthaputra, 2003). CFD modelling is more popularly used now a days because of its time reduction and cost reduction in creating new layouts. In addition, there is a possibility to analyze multiple number of problems where the level of detail is practically unlimited and visual representation is better.

For this study, the wind pattern of the multi storied apartment at different level is tested using CFD. Cradle is selected as a simulation tool because of its reliable outcomes and speed. Cradle scSTREAM has gained popularity especially in South east Asia due to its accuracy, user friendliness and visual representation (Kim 2016; He et al.2016; Durva et al. 2020). In addition, it is possible to conduct simulation using scSTREAM in personal computers due to its advanced mesh algorithms.

Airflow was selected for the study due their strong effect on human beings as well as microclimate on a warm & humid climate. Average wind speed for the month of March, April and May was chosen to carry out the simulation. Wind speed 35m above ground and 3.5m /s was considered for simulation which is extracted from the meteorological department of Bhubaneswar.

Model geometry

AutoCAD two-dimensional drawing was imported to scSTREAM and scaled to actual dimensions. Preprocessor is used to create the 3-dimensional geometry and meshing for the CFD simulation. To simulate the outdoor wind flow for each zoning scheme, the studied multi storied apartment building with several blocks are modelled as solid blocks. The buildings placed beyond the sites are ignored.

Computational domain

According to the Best practice guideline for CFD simulation of flows in urban environment, the distance between building and the outflow boundary of the computational domain has to be at least 5 times the height of the building at the sides. The exit of the domain at the leeward side has to be at least 15times the building height (Franke et al. 2007). These guidelines are strictly followed.

Computational grid

Accuracy of CFD solutions depends on its grid size and grid numbers. Uniform structured grids are better in terms of accuracy, but its large computation cost is impractical for most urban wind analysis scenario (Franke, et al., 2007). To overcome this large computation cost, non-uniform grids are used in following manner: i) high resolution grids are generated around the close vicinity of the subject, and ii) the grids get coarser (with reasonable gradient) as they go further from the subject (Wu, Yang, Tseng, & Liu, 2011). Rough grids and detailed mesh were created for the buildings. According to the best practice guideline, a minimum of 10 grids are required between the buildings (Franke, et al., 2007). 0.7m (2 ft) grids are created near to the subject for the simulation. Non uniform grids are created for the outer domain maintaining the geometric ratio at 1.05 to achieve finer grids. Hence grids next to the central group of volumes are similar in size and grids those are further away from the central volumes gets larger in size. Similar size grids are assigned for vertical height as well. The gradation of grid sizes is shown in Table 7.

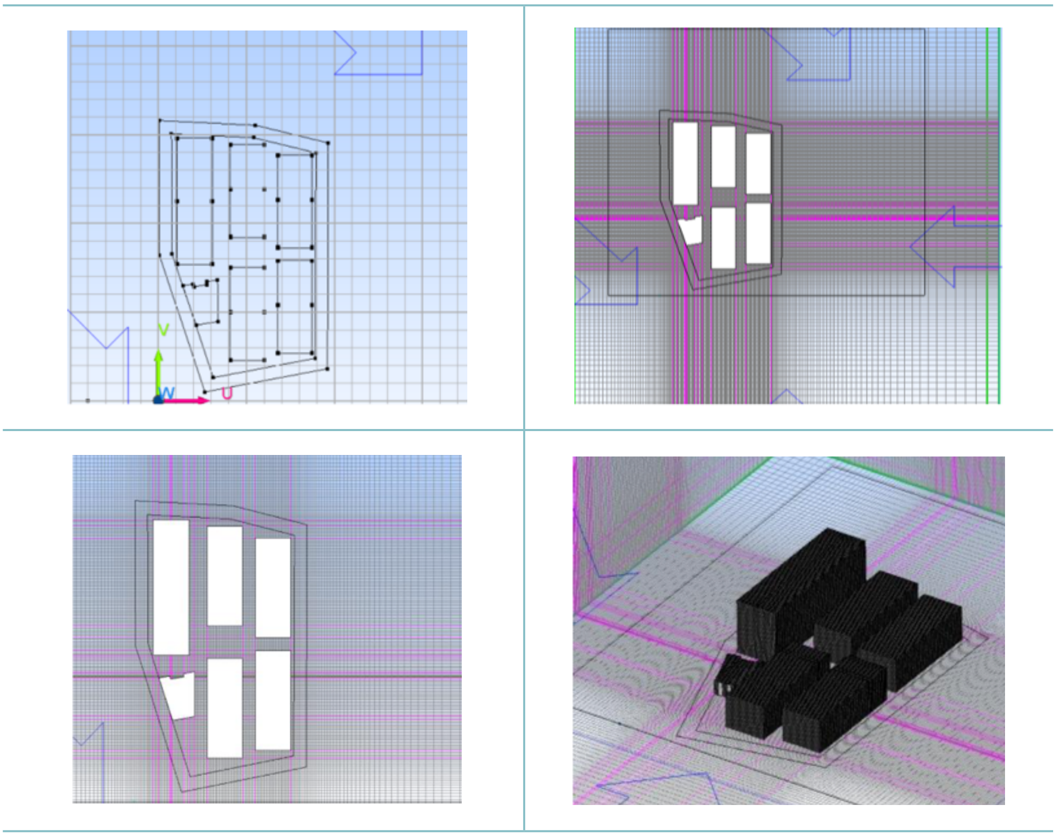


Table 7

Computational grid generation

Boundary condition

Both south and south west face of the domain is chosen as the velocity inlet for hypothetical cases as both are the prevalent wind direction of Bhubaneswar.

Convergence criteria

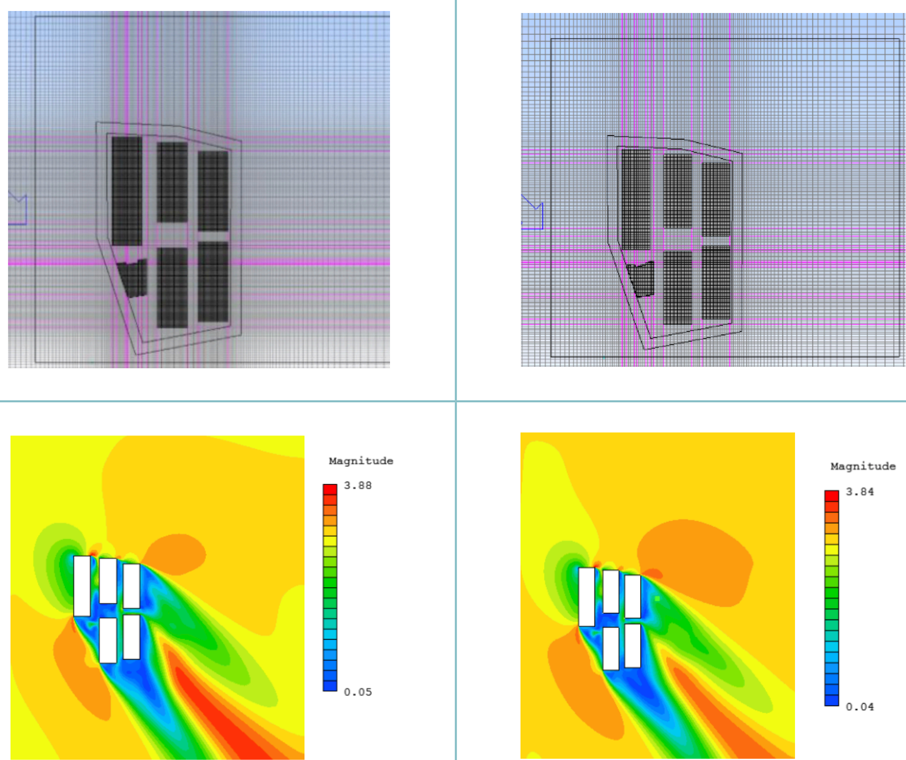
For simulation, the study has convergence after 600 repeats. Following convergence, the results are post processed using STpost.

Grid independent test

A grid independent test was performed before using the mentioned grid generation methodology. The main concern regarding this methodology is that whether 10 grids between two buildings is reasonable or not. First a simulation environment was created based on this methodology with 10 grids. Then a second simulation environment was created where 15 grids were assigned between two buildings. The velocity difference between these two scenarios is observed to be 1.0% (Table 8).

Table 8

Grid independent test



Validation of the simulation tool

Four locations are been chosen inside the development and the wind speed and wind direction is measured in certain particular time at a height of 1.1 m from the ground level by using four separate handheld anemometers with an accuracy of ±5%. Due to the limited number of instruments, it was not possible to do simultaneous measurements. But the wind speed measurements in the four locations were performed within half an hour. The measurements were repeated for morning, afternoon, evening and night, four times in a day for seven days. The average wind speeds were calculated and compared against the simulated results. Location 1 measurement was been used by the tool to calculate the wind speed of the remaining three locations in simulation. A maximum of 0.5m difference in wind speed is observed for two locations where the wind speed is low (Fig. 6). This might be because of a slight shift from the exact location where the wind speed was physically measured.

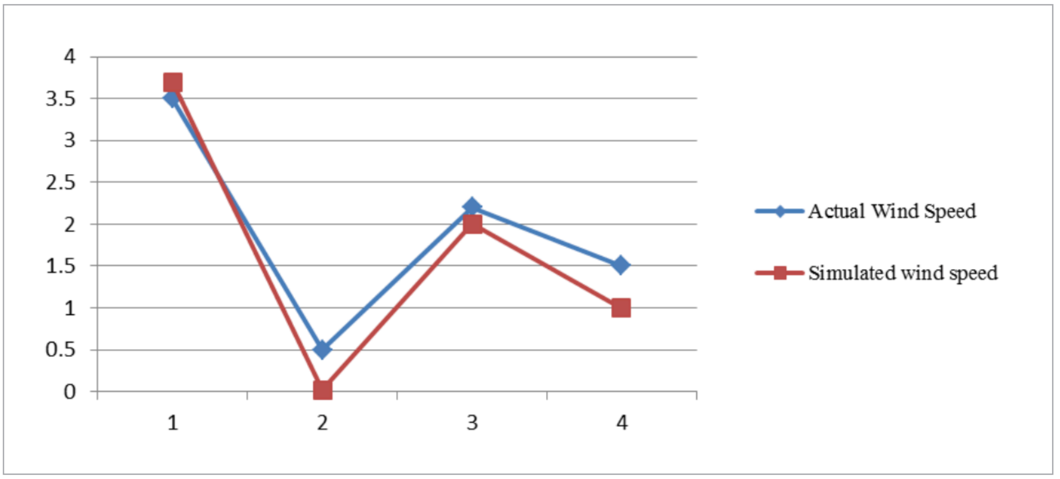


Fig. 6

Actual vrs simulated wind speed

Observations and analysis

After validating the simulation tool, the analysis is performed using the CFD. The study is performed in two stages. In the first stage, the wind shadow extent is identified for all the scenarios in the leeward side of the buildings where there is poor ventilation. Placing buildings in that zone can create unhealthy situation. In the second stage, the wind flow in between buildings are measured. An ideal ground coverage has minimum wind shadow zone and better ventilation between buildings.

Base case

The base case of Bhubaneswar, Club town has the ground coverage as high as 46% since the building codes does not specify any control over coverage for different types of developments. Fig. 7 shows the base case scenario in different levels +1.0m, +3.3m and +6.3m above the ground level. It is quite crucial to observe the pattern and magnitude of outdoor air velocities at different levels because an adequate outdoor air velocity raises the occupant's comfort level at the indoors.

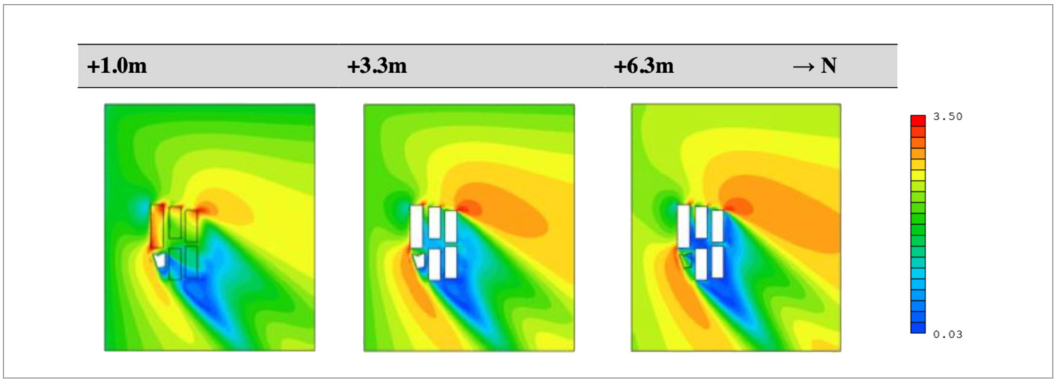


Fig. 7

Wind contour patterns for the base case

Wind shadow condition when wind is from south and parallel to the shorter face of the blocks

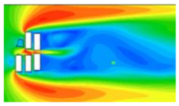
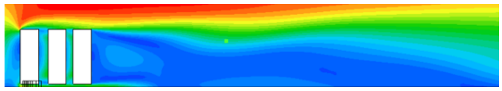
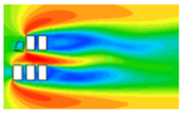
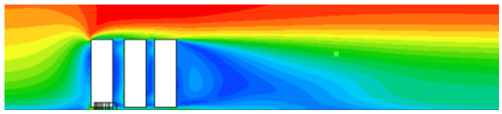
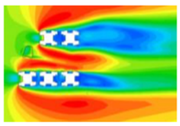
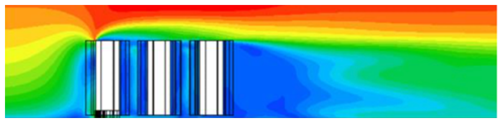
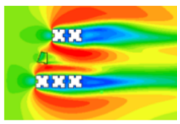
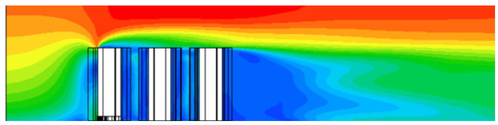
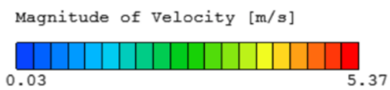
In hypothetical cases, buildings are arranged in such a way that the windward side is unobstructed for the wind flow. In the first case, a south direction wind is utilized to analyze the wind pattern around the block where the longer side of the buildings faces the South and North direction. It is observed that the wind shadow in the leeward side is drastically reduced when the ground coverage of the blocks is reduced to 4 dwelling units in place of 6 dwelling units when wind is parallel to the shorter face of the buildings. The wind shadow zone is observed to be 2-3 times the height of the blocks when the ground coverage consists of 4-unit linear blocks with 30% coverage. With

6-unit linear blocks the wind shadow zone is observed to be almost 6-7 times of the building height. Similarly, for tower blocks, 4 dwelling unit towers perform better in place of 6 dwelling units. The shadow extent is observed to be 3-4 times the building height for 6-unit blocks whereas, it is 2-3 times of the building height for 4-unit tower blocks (Table 9).

The wind shadow zone at the rear also meant to have least ventilation in those areas. Hence a relationship is established between ground coverage and rear setback. As a result, not only the building height but also the ground coverage as well as the building form is observed to have a critical role to play in deciding the setback of buildings.

Table 9

Wind pattern with variations in Ground Coverage when wind is from South and is parallel to the shorter face of the blocks

Details of the units	Layout	Cross section →N
6 DU linear (40%)		
4 DU linear (30%)		
6 DU tower (35%)		
4 DU tower (25%)		
		

Wind shadow condition when wind is from South and perpendicular to the shorter face of the blocks

In the second case, a south direction wind is utilized to analyze the wind pattern, but the buildings are arranged in such a way that the shorter side of the buildings faces the South and North direction. Since both the 4-unit blocks and the 6-unit blocks are having a similar width, the shadow extent is observed to be the same in both the cases. It is revealed that the wind shadow in the leeward side is drastically reduced for both 6 unit and 4-unit linear blocks. The wind shadow zone is observed to be 2-3 times the height of the blocks when the ground coverage consists of 4 unit and 6-unit linear blocks. However, the shadow is 6-7 times of the height of the blocks for both the tower blocks. Though the tower block has a square plan, the wind shadow zone has reduced in the former case due to the strategic location of open space in the windward direction. Hence it is inferred that providing an open space in the wind ward direction without obstruction contributes in reducing the shadow extent to a larger extent (Table 10).

Wind direction is another critical factor detected to have implication on deciding the rear setbacks.

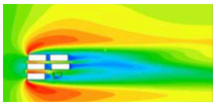
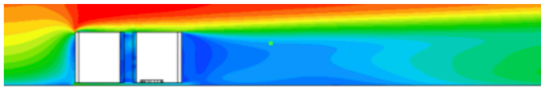
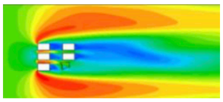
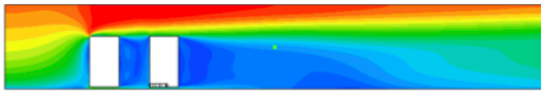
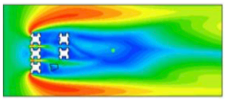
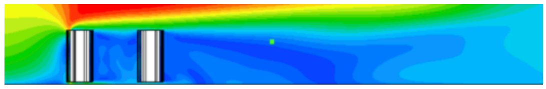
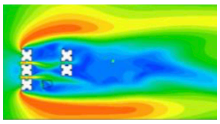
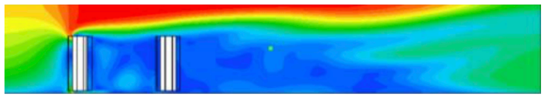
Details of the units	Layout	Cross section →N
6 DU Linear (40%)		
4 DU Linear (30%)		
6 DU Tower (35%)		
4 DU Tower (25%)		
		Magnitude of Velocity [m/s]  0.03 5.58

Table 10

Wind pattern with variations in Ground Coverage when wind is from South and is perpendicular to the shorter face of the blocks

Wind shadow condition when wind is from southwest and aligned to the blocks

In the third case, south west prevailing wind is used to analyze the wind pattern. Tower block is observed to be a better performer. However, the wind shadow zone is observed to be aligned to the wind direction. The wind shadow extent is observed to be 2 times of the building height for both linear blocks and tower blocks in South as well as East directions except at the corner (Table 11).

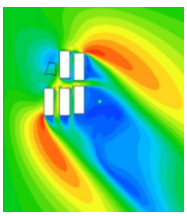
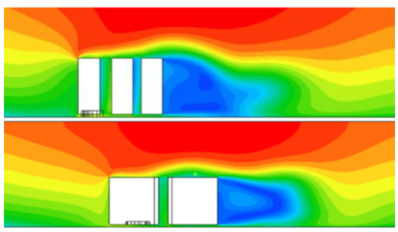
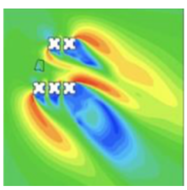
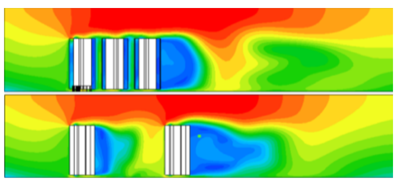
Details of the units	Layout	Cross section
6 DU Linear (40%)		
4 DU Tower (25%)		
		Magnitude of Velocity [m/s]  0.05 4.77

Table 11

Wind pattern with variations in Ground Coverage when wind is from Southwest

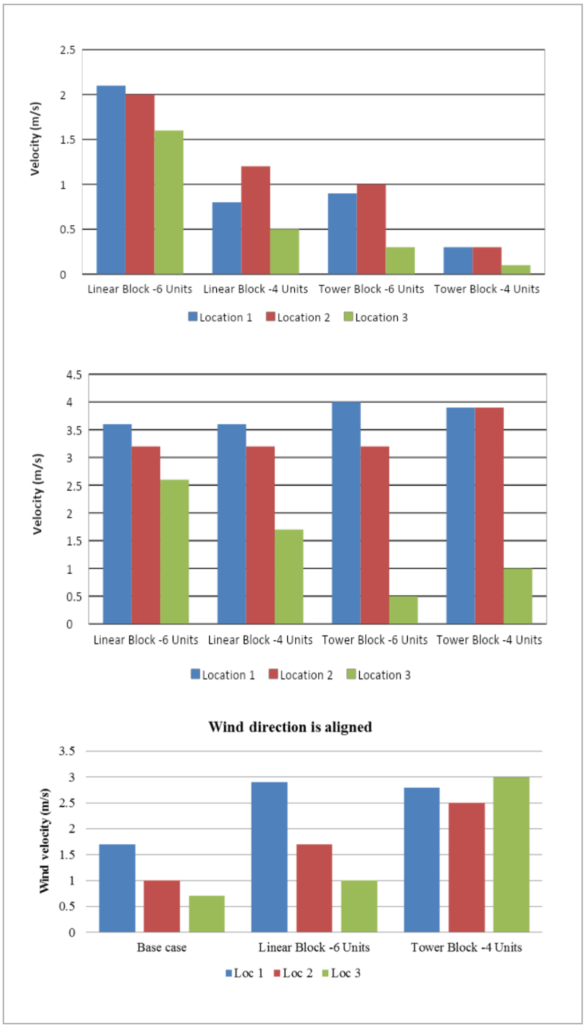


Fig. 8

Wind speed in between the blocks for Scenario 1,2 & 3 @ 15.3 m from ground level

Wind flow in between the blocks

For scenario 1, wind movement in between the blocks for 6 unit block is observed to be significantly better than their 4 unit counterparts. Channelling of wind movement along the longer surface might be the reason for better wind movement. The wind speed in between the blocks are measured at the level of 15.3 m from the ground level is displayed in Fig. 8. 4 unit tower blocks are observed to be the worst performer in terms of wind movement.

For the second case, the wind tries to penetrate through the linear blocks creating uniform ventilation throughout the development. The gap between the blocks seems to be well ventilated. Longer blocks provide better wind flow in comparison to shorter blocks. However, in contrast the tower blocks seem to be worse in performance in respect to the wind flow. The gap between the towers does not seem to bring in enough wind to the domain because of their built form.

The 6 unit blocks, in spite of having highest ground coverage have lowest wind shadow zone when wind is parallel to its longer face. In addition, wind movement in between the blocks for the 6 unit blocks are significantly better than any other scenario. The linear blocks try to bring in enough wind to the domain. Bringing in more wind in the domain also contributes to reducing the wind shadow extent. Hence the study revealed that, a denser environment not necessarily obstruct wind all the time. The building orientation based on prevailing wind direction is an important consideration to created better ventilated spaces.

The research tries to identify the wind shadow zone as the rear setback where no habitable buildings should be built. The suggestive bye law decides the rear setback and ground coverage considering each building form and wind direction.

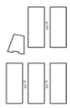
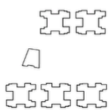
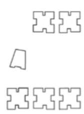
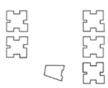
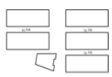
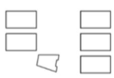
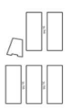
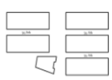
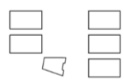
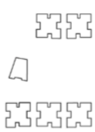
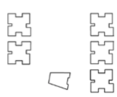
Conclusion

Two types of building forms prevalent in Bhubaneswar are analyzed to understand how varying the ground coverage affects the wind pattern of the development. The first one is a linear block and the second one is tower block; each typology is having six and four units in each block. Two wind directions are considered for simulation, one is from South side and the second one is from South west; both are prevalent wind directions of Bhubaneswar. Building orientation differs for each wind direction, in the first the shorter side is parallel to wind direction and in the second the shorter side is perpendicular to wind direction.

It is inferred from the study that, wind direction, layout of the blocks as well as the typology of the blocks play an important role in bringing ventilation to the domain. Hence, bye-law should consider all of those factors while formulating the building code of a particular place. There is a strong relationship observed with the front and rear setback and wind direction. The results provide the following recommendations (Table 12):

1 Open space to be located in the windward side of the development
2 The direction of the wind and the typology should decide the rear set back. Ideally, the rear setback should be the opposite to the wind direction and not the rear side of the parcel in a true sense.
3 Front setback, which falls in the direction of the wind can have least setback.

Table 12
Recommendations

Prevailing wind direction	Building arrangement and typology	Building foot prints	Leeward side setback	Suggestive ground coverage
→		Linear blocks with 6 units	6-7 times of the building height	40%
→		Linear blocks with 4 units	2-3 times building height	30%
→		Square Tower of 6 units blocks should have un obstructed open space along the wind direction	3-4 times building height	35%
→		Square Tower of 4 units blocks should have un obstructed open space along the wind direction	2-3 times building height	25%
→		Not preferred		
→		Linear blocks with 6 units	2-3 times building height	40%
→		Linear blocks with 4 units	2-3 times building height	30%
↘		Linear blocks with 6 units	2 times of the building height	40%
↘		Not preferred		
↘			2 times of the building height	25%
↘		Not preferred		

Limitation

1 Only ground coverage is considered for this analysis. Altering building height or distance between buildings can provide slightly different result. While framing the bye-law all the parameters should be considered so that a holistic code can be drawn.

2 Blocks are placed in grid iron pattern only. Different layout pattern may provide different result.

3 The study considered the smallest possible parcel for analysis. By considering larger parcels and different layouts, a more accurate conclusion can be drawn.

4 Solar protection is not considered in the analysis. Both solar protection and ventilation are important aspects for tropical warm and humid climate.

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