Relationship between Urban Morphological Properties and Ventilation in the Intensely Developed Areas of Inner Bangkok

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Abstract

Bad urban ventilation is a major intimidation to Bangkok urban air environments. Nowadays, not only lack of research progress in this area due to the complexity of urban fabric, but also lack of awareness and knowledge about affiliations between urban morphological properties and human level air ventilation at microscale is a key factor that contravenes mitigation efforts in dense areas. The objective of this study is to find a relationship between urban morphological properties and urban air ventilation in various intensely developed environments of inner Bangkok that are investigated through computer simulation of field measurements secondary data input and flow analysis calculation on the basis of the geometry of the urban fabric. With regard to the innumerable number of parameters collected throughout a literature review, this study aims to identify the most important urban morphological parameters at urban block level (at the human level above ground) that affect air ventilation in Bangkok area. This study is the first part of the identification process of urban morphological properties of block types that may correlate with urban air ventilation. The results are as follows: "high density - low rise" type with parallel-to-prevailing-wind orientation (block no. 26) has the best urban ventilation efficiency, followed by "high density - high rise" type with a single, large and tall building, "high density - low rise" type with deviating-from-prevailing-wind orientation, "high density - high rise" type with parallel-to-prevailing-wind orientation, and "high density - high rise" type with deviating-from-prevailing-wind orientation, respectively. Building height and orientation are the two factors that are attributed to the parameterization of human level air ventilation.

Keywords: *Urban morphological properties, urban ventilation, intensely developed areas, inner Bangkok.*

1. Introduction

The urban ventilation directly influences the health of cities' inhabitants and their well-being (Kuttler 2004). The link between the built environment and people's physical and psychological health are rooted in 19th century industrial cities. Unsanitary and overcrowded slum conditions facilitated the transmission of air borne diseases such as influenza and tuberculosis. By the mid-20th century, many cities' settlements were characterized by improved living conditions. Over the past few decades, urban planning has moved beyond thinking primarily on "urban ventilation". These changes highlight common interest about the impact of built environments on health and the role good urban design policies play in creating positive health outcomes at the population level.

Urban ventilation is becoming an important concern due to the serious urban air environment problems. The cause of rapidly growing metropolitan infrastructures is increasing the roughness of urban surfaces which obstructs urban wind speeds. The work on the understanding and ways of dealing with the urban air ventilation issue has been progressing significantly. The most critical problem is with the densest and most congested urban areas. The importance of urban redevelopment design is that it could possibly make a linkage between public health and urban planning and explore collaborative strategies and tangible actions for healthier population. Thus the systematic evaluation of urban ventilation performance is becoming an urgent problem and a challenge.

Urban microclimate (including urban ventilation) can be improved, worsened or mitigated by urban planning (Fehrenbach *et al*. 2001; Gomez-Chova *et al*. 2006). An inconsiderate urban plan can make inhabitants suffer from inadequate ventilation. Currently, many urban planning researchers focus their efforts on studying urban ventilation by measuring ventilation efficiency within urban domains. For most urban climate models, methods for inventorying the physical characteristics of the urban environment have been developed (Ellefsen 1991; Voogt and Oke 1998). Therefore, urban planners need the real information (on prospered scale) to address the urban microclimate on their spatial plan at the stage of redeveloped design. To do so, urban planners need sufficient, accurate and reliable information on the real urban morphological properties that affect urban ventilation. Nowadays, there is still lack of real urban morphology studies because architects mostly rely on assumed unreliable data by using clusters of plain cubic boxes rather than using the urban morphology of real districts.

The overall purpose of this study is the presentation of an overlaid urban roughness mapping in a Bangkok large study area. The proposed method aims at studying the airflow in 5 morphological block heterogeneity types in urban areas by investigating urban design parameters and evaluating how morphological property parameters in urban blocks influence urban ventilation efficiency in order to find out key parameters for modifying and improving the planning in said urban areas. An effective environmental planning and management process will help decision makers to formulate and implement strategies to improve urban ventilation and to achieve a sustainable growth pattern. This study considers just a part of the complex airflow problem because the investigated urban design parameters are limited to 5 parameters as follows: block size; floor area ratio (FAR); open space ratio (OSR); ratio of total skin surface area of urban block to lot area (urban rugosity); and the number of buildings per block lot (building density) and building surface roughness. The limitation of this study is that it is using only one direction for the main wind which presumably blows from the south to the north.

2. Methodology

Computer fluid dynamics (CFD) simulation of urban roughness using official buildings map information based on Geographic Information System (GIS) data from the Bangkok Metropolitan Administration (BMA) is one approach that can analyze the airflow quantitatively with respect to spatial flow changes in actual scale. CFD was used to build a mathematical representation and numerically solve the governing equations, including different forms of the Navier-Stokes equations over a discrete flow field on the basis of a finite volume method. This approach was used because it allows a wide range of applications such as irregular geometries, turbulent airflow, and open flow inlets and outlets. At present, the studies of urban block forms are limited to groups of plain cubic boxes, rather than having urban blocks in real districts and real meteorological wind data input. However, such a simplified approach does not provide enough information for actual evaluation. In this study, the CFD technique with a *k*-epsilon model for high Reynolds number was used for the evaluation. Realistic urban block models of typical blocks existing in the intensely developed area of inner Bangkok were adopted and 5 reference cases with varied urban parameters as mentioned above were simulated.

3. Data

The overall data and analysis method are handled by two distinct software parts, GIS urban roughness block and CFD simulation.

The summary of the combined influencing factors of terrain features and urban built form structures on wind field and urban ventilation is based on topographic information and surface properties derived from a digital terrain model and block map data from the Bangkok Metropolitan Administration. "Friction force" is the key evaluation parameter and the friction force of the earth surface in urban scale is called "surface roughness" while "ventilation class" is the component required to delineate urban ventilation. Ventilation classes and urban fabric built forms can describe characteristic combinations of ventilation factors controlling local wind fields and vertical air mass exchange processes. The methodology is based on performing urban block spatial analysis with all independent ventilation factor variables, resulting in typical and distinctive flow patterns and ventilation conditions.

For the analysis of the required input parameters in the CFD model, extensive fluid modeling studies of flow and dispersion around obstacles are needed as cities are composed with low and high buildings, arrayed in blocks and intersected by streets. The complexion of urban surfaces strongly influences the urban boundary layer and urban airflow (Roth 2000). The buildings can induce drag and increase turbulent eddies. All this affects the urban roughness sublayer and vertical wind velocity profiles.

4. Study Area

Bang Rak District is Bangkok's central downtown business district (CBD). It contains the maximum number of tall buildings. This complex urban topography strongly affects the spatial pattern of air quality which is determined by the wind regimes and how they interact with their urban topography (Jarnagin 2010).

This study is using Bang Rak city blocks as units for analysis. A 'city block' is an area in a city surrounded by streets and usually containing several buildings. Bang Rak district contains 98 city blocks. The average block size is approximately 30,000-45,000 square meters. Although the study area is limited to Bang Rak District, this study is obviously relevant for other urban regions within the capital city as similar high density urban block arrangements can typically be seen in many Bangkok districts.

5. Project Set-up and Data Preprocessing

5.1 GIS Preprocessing

Overlay in GIS map is the process of taking different key variables of maps of the same area and overlaying them one on top of the other to form a new map layer. In urban planning, the Potential Surface Analysis (PSA) technique is widely used for analysis. This method requires an appropriate ranking for weighting the PSA factors on the basis of the physical data of the study area. The details of overlay factor mapping are as follows:

- administrative boundaries;
- natural environment;
- built environment;
- public utilities and facilities; and
- transportation.

However, PSA is a complex analytical technique and uses a variety of parameters for its calculations. The Geographic Information System (GIS) plays an important role in the analysis to improve the accuracy of weights and parameters in the PSA approach.

The representation of ground surface landforms, as shown in Fig. 1, is accomplished with the use of Digital Terrain Model (DTM) which is commonly used to produce topographic maps. With the PSA technique, the analysis is separated into two parts:

- ❖ Part 1, administrative boundaries, the focus is on weighing 3 variables with selected data:
  - floor area ratio (FAR);
  - open space ratio (OSR); and
  - ratio of total skin surface area of urban block to lot area (urban rugosity).
- ❖ Part 2, built environment, the focus is on weighing 3 variables with selected data:
  - total usable area;
  - the number of buildings per block lot (building density); and
  - building surface roughness.

The obtained results represent the high density urban block arrangements that can be seen in Bang Rak District. The first block type is "high density - high rise" (Fig. 2) and the second block type is "high density - low rise" (Fig. 3).

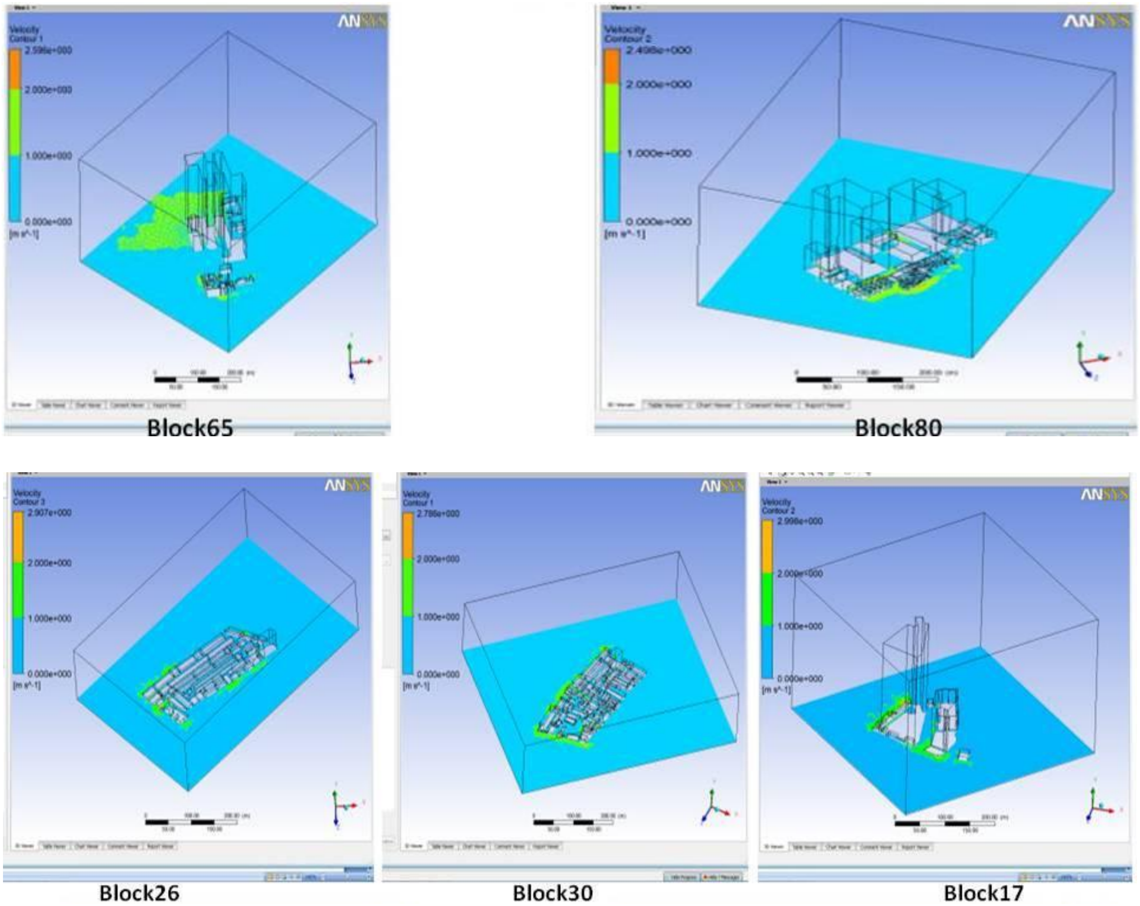


Fig. 1. Overlay process on GIS map with Digital Terrain Model (DTM).

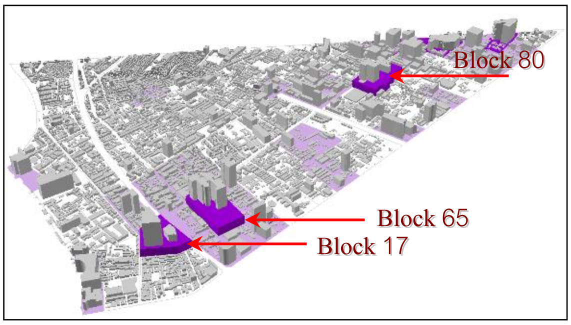


Fig. 2. Morphological properties of urban block type "high density - high rise".

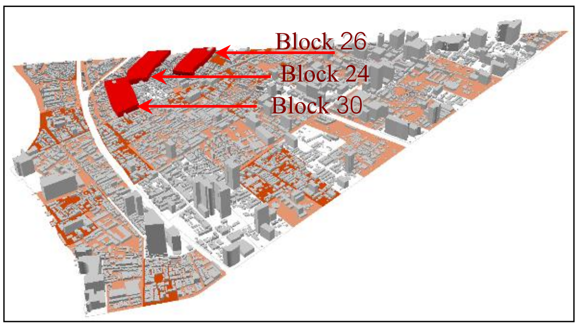


Fig. 3. Morphological properties of urban block type "high density - low rise".

6. Morphological Properties

6.1 Block Type "High Density - High Rise"

The top three "high density - high rise" blocks are no. 17, 65 and 80 with the following details (Fig. 4).

6.1.1 Morphological properties of block no. 17: The block area is 33,942.94 square meters, floor area ratio (FAR) is 16, open space ratio (OSR) is 0.0003, total building surface (rugosity) is 4.41, building surface roughness is 1,326,190 square meters. The block lot (building density) comprises 53 buildings with 3 extremely large building clusters, such as 63-storey Silom Precious building with total building surface of 670,867 square meters, and 30-storey and 10-storey Lert Sin Hospital buildings with total building surface of 270,851 square meters and 113,235 square meters, respectively. The rest has average building surface from 273 to 2,974 square meters. The average number of floors per building is 1-5 floors.

BLOCK PER BUILDING	Block 17	Block 65	Block 80
BLOCK PER AREA (SQ.M.)	33,942.94	43,771.91	42,574.92
F.A.R.			
F.A.R. OF BMA	*10*	*10*	*10*
F.A.R OF BLOCK	16.04	12.05	10.56
O.S.R.			
O.S.R. OF BMA	*3*	*3*	*3*
O.S.R. OF Block	0.003	0.005	0.008
RUGOSITY	4.41	4.58	4.28
BUILDING DENSITY	53	56	111
THE TOTAL BUILDING USABLE AREA			
- GENERAL BUILDING	50	51	103
- TALL BUILDING	0	0	0
- LARGE BUILDING	0	2	2
- EXTREME LARGE BUILDING	3	3	6
SURFACE AREA OF BUILDING			
- AVERAGE	33,022.92	31,085.74	13,420.26
- MAXIMUM	1,326,190.89	875,856.23	696,909.14
BUILDING STOREY	63	56	50

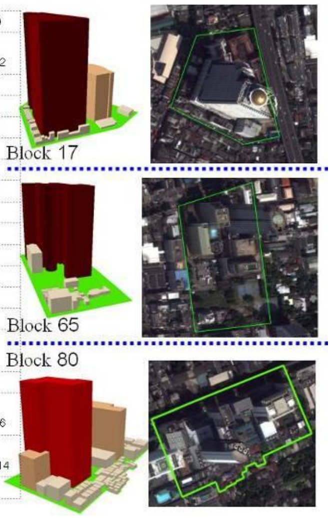


Fig. 4. Morphological properties of block no. 17, 65 and 80.

6.1.2 Morphological properties of block no. 65: The block area is 43,771.91 square meters, floor area ratio (FAR) is 12, open space ratio (OSR) is 0.0005, total building surface (rugosity) is 4.58, building surface roughness is 875,856 square meters, the block lot (building density) comprises 56 buildings with two large building clusters and three extremely large building clusters, such as 56-storey and 14-storey Holiday Inn Crown Plaza buildings with total building surface of 540,178 and 150,257 square meters, respectively, and 56-storey Silom Galleria building with total building surface of 875,856 square meters. The rest has average building surface from 101 to 5,572 square meters. The average number of floors per building is 1-5 floors.

6.1.3 Morphological properties of block no. 80: The block area is 42,574.92 square meters, floor area ratio (FAR) is 10, open space ratio (OSR) is 0.0007, total building surface (rugosity) is 4.28, building surface roughness is 696,909, square meters, the block lot (building density) comprises 111 buildings with two large building clusters, such as 55-storey United Center building with total building surface of 560,190 square meters, and 30-storey CP Tower building with total building surface of 339,946 square meters and the Liberty Square Tower with 174,901 square meters, respectively. The rest has average building surface from 172 to 7,945 square meters. The average number of floors per building is 1-5 floors.

6.2 Block Type "High Density - Low Rise"

The top three "high density - low rise" blocks are block no. 24, 26 and 30 with the following details (Fig. 5).

6.2.1 Morphological properties of block no. 24: The block area is 36,931.34 square meters, floor area ratio (FAR) is 2, open space ratio (OSR) is 5, total building surface (rugosity) is 4.82, building surface roughness is 22,440.31 square meters, the block lot (building density) comprises 350 buildings, two large building clusters, such as 6-storey PS House apartment buildings and (3-5)-storey shop houses. The rest has average building surface from 166 to 6,795 square meters. The average number of floors per building is 1-5 floors.

6.2.2 Morphological properties of block no. 26: The block area is 31,601.72 square meters, floor area ratio (FAR) is 1, open space ratio (OSR) is 3, total building surface (rugosity) is 4.24, building surface roughness is 35,976.03 square meters, the block lot (building density) comprises 439 buildings, one large building cluster, 6-storey CSP Mansion buildings with building surface of 11,560 square meters, one extremely large building cluster, 15-storey Thai-Shinawatra building, and mostly (3-5)-storey shop houses. The rest has average building surface from 155 to 2,016 square meters. The average number of floors per building is 1-5 floors.

BLOCK PER BUILDING	Block 24	Block 26	Block30
BLOCK PER AREA (SQ.M.)	36,931.34	31,601.72	41,320.26
F.A.R.			
F.A.R. OF BMA	*10*	*10*	*10*
F.A.R OF BLOCK	2.3	1.84	1.85
O.S.R.			
O.S.R. OF BMA	*3*	*3*	*3*
O.S.R. OF Block	5.28	3.83	6.86
RUGOSITY	4.82	4.24	3.89
BUILDING DENSITY	350	441	415
THE TOTAL BUILDING USABLE AREA			
- GENERAL BUILDING	348	439	411
- TALL BUILDING	0	0	0
- LARGE BUILDING	2	1	4
- EXTREME LARGE BUILDING	0	1	0
SURFACE AREA OF BUILDING			
- AVERAGE	1,132.87	629.75	842.18
- MAXIMUM	22,440.31	35,976.03	23,553.49
BUILDING STOREY	6	15	13

Fig. 5. Morphological properties of block no. 24, 26 and 30.

6.2.3 Morphological properties of block no. 30: The block area is 23,553 square meters, floor area ratio (FAR) is 1, open space ratio (OSR) is 6, total building surface (rugosity) is 3.89, building surface roughness is 35,971.03 square meters, the block lot (building density) comprises 415 buildings, four large building clusters, such as 13-storey Pramuan apartment buildings with building surface of 23,553 square meters and 6-storey police residence buildings with building surface of 17,220 square meters. The rest has average building surface from 132 to 4,629 square meters. The buildings are mostly (3-5)-storey shop houses. The average number of floors per building is 1-5 floors.

The morphological properties of block no. 17, 65, 80, 26 and 30 were chosen for the airflow analysis. Block no. 24 and block no. 26 have approximately the same morphological properties and block no. 26 was used in this study.

7. CFD Preprocessing

7.1 CFD Data Input

This study is based on measurements undertaken in intensely developed urbanized areas by using ANSYS Fluent® CFD software (ANSYS 2011) to simulate 5 block models (block no. 17, 65, 80, 26 and 30). The input conditions are the same for all models: wind inlet, the velocity input is 2 m/s; and the pressure was set to be zero Pascal (Pa) at the free outlet open to the atmosphere. The wind outlet pressure setting is: Outlet Back, Outlet Right, Outlet Left, and Outlet Roof = 0 Pascal. For all 5 block models, the computational boundary domain size is approximately 10 times of the study object. The processing steps of CFD analysis are as follows:

- Problem statement;
- Mathematical model;
- Mesh generation nodes/cells;
- Space discretization;
- Time discretization algebraic system;
- Iterative solver discrete;
- CFD software implementation;
- Simulation run parameters;
- Post processing visualization, analysis of data; and
- Verification model validation/ adjustment.

7.2 CFD Framework

The principles of the airflow "are governed by the basic physical laws of conservation of mass, momentum and energy. The conservation laws are expressed mathematically by means of balance differential equations, which describe the flow process in general conditions in an infinitesimal control volume. Simpler equations are obtained by implementing the specific flow conditions characteristic of a chosen control volume." (Matousek 2004)

Balance as per the energy conservation law must be present so that the mass flow inlet is equaled to the mass flow outlet. Therefore, the design and construction of a quality grid is crucial to the success of the CFD analysis. For this study, the finding of an appropriate choice of grid type is dependent on: geometric complexity, flow field, and cell and element types supported by the solver. The grid designates cells or elements on which the flow is solved in order to establish suitable meshing. The validation of simulation results was performed by using plots to check the model assumptions and also plots of residuals to check the convergence. For this study, the mesh consisted of 1,000,000 - 9,000,000 tetrahedral cells and approximately 2,000,000 nodes. It kept the skewness value under 0.85. The standard *k*-epsilon turbulence model was used to account for the turbulent airflow. The solution was considered convergent when the solution residuals reached the default values of less than 0.001 for the flow equations and less than 0.0000001 for the energy equation. The simulations reached convergence after roughly 2 hours and approximately 1,000 iterations on a computer with eight 2.66 GHz processors and 3.25 GB of RAM.

8. Measurements

In summary, the main steps of this study involve:

- Two-dimensional CFD-based parametric analysis of models of airflow patterns;
- Contour plot for overall flow observation at a cutting plane height of 1.5 m above ground level (having the most significant impact on pedestrians and urban inhabitants); and
- CFD simulation results showing both velocity and pressure at all points, especially at inlet and outflow planes.

The flow results can be seen by choosing Top view or Side view and can be categorized by using high or low velocity zones. These results can be used to investigate the block types having the worst flow by observing the velocity loss at the built form of each block. The CFD-based parametric analysis is used to investigate the main key factors affecting the urban ventilation.

For this study, the results were presented in terms of wind velocity (m/s) and percentage of amount of velocity isovolume (%). By definition, the CFD isovolume is computed as the volume of velocity elements (as a percentage of the total). It can be counted as the percentage of velocity inertia of each grid volume of the mesh compared with the velocity of the whole urban volume.

9. Results and Discussion

The comparison of flow simulations among five urban block types shows that the “high density - low rise” type has many air reattachment points and air stagnant zones (see Fig. 6) with the following details.

The “high density - low rise” type has larger amount of air reattachment points and air stagnant zones (zero wind velocity) than the “high density - high rise” type. In the graph for isovolume V = 0, column no. 1 and 2 (for the “high density - low rise” block no. 26 and 30) are higher than column no. 3, 4 and 5 (for the “high density - high rise” block no. 17, 65 and 80). On the basis of the observation of the velocity loss at the built form of each block, it means that the urban ventilation of the “high density - low rise” block type is worse than the “high density - high rise” block type for the worst flow (in the graph for isovolume V = 0, column no. 3 is the lowest).

9.1 Isovolume Graph for V = 0 m/s

Block no. 17 has the least amount of air reattachment points and air stagnant zones (zero wind velocity) followed by block no. 65, 80, 26 and 30, respectively (Fig. 6). The percentage of volume per total domain boundary of block no. 26, 30, 17, 65 and 80 is 5.09445×10^{-2}%, 5.87698×10^{-2}%, 3.80433×10^{-2}%, 4.45664×10^{-2}% and 4.49521×10^{-2}%, respectively. The difference in block orientation does matter as in between the “high density - low rise” block configurations block no 30 has better urban ventilation than block no. 26 since the value in column no. 2 is greater than that in column no. 1 in the graph for isovolume V = 0 (Fig. 6). The orientation of block no. 26 is quite parallel to the main wind direction blow from the south to the north while the orientation of block no. 30 rather deviates from the main wind direction according to the details of morphological properties of different blocks shown in Fig. 5.

Legend: In Figs. 6-8, column no. 1 is block no. 26, column no. 2 is block no. 30, column no. 3 is block no. 17, column no. 4 is block no. 65, and column no. 5 is block no. 80.

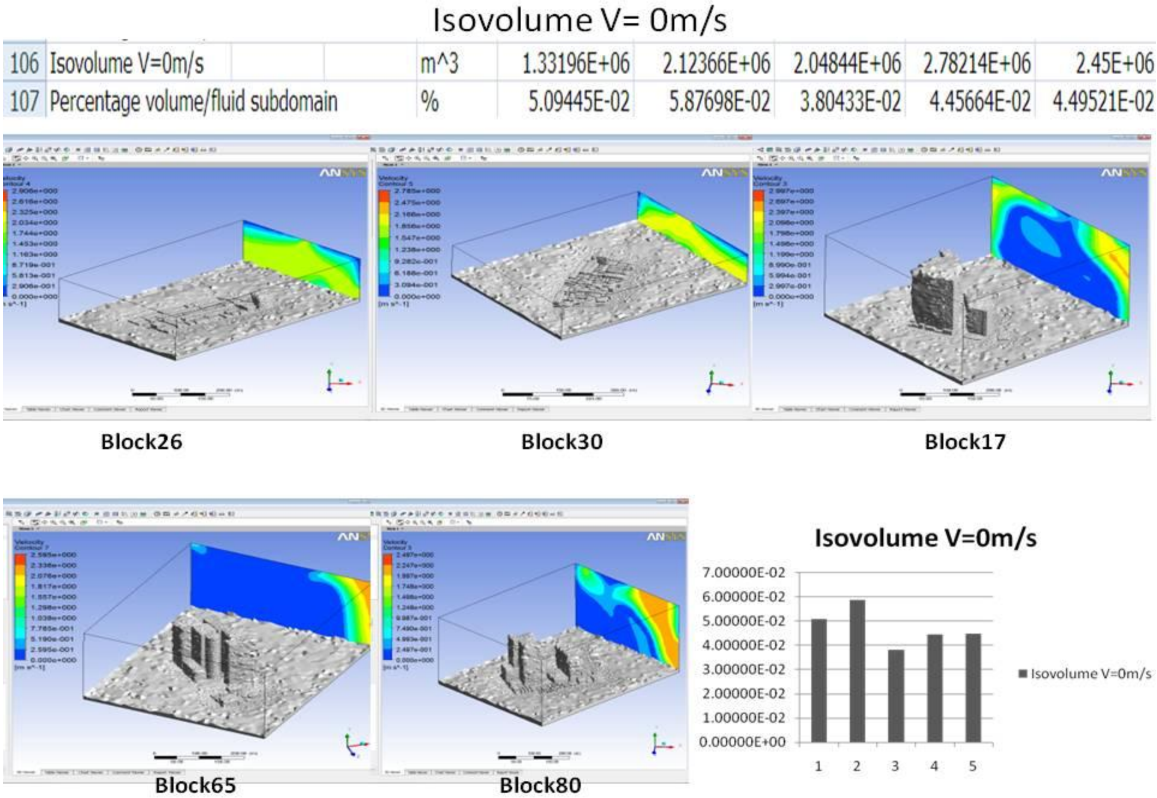


Fig. 6. Comparison of flow simulations for 5 urban block types.

9.2 Velocity Graphs for $V > 2$ m/s, $V = 1$-2 m/s and $V < 1$ m/s

Block no. 17 has the best wind velocity, higher than other blocks, followed by block no. 80, 30, 26 and 65, respectively, according to the graph for $V > 2$ m/s in Fig. 7. It means that the "high density - high rise" block type with a single, large and tall building type (according to the details of morphological properties of different blocks shown in Fig. 4) can catch the wind and enhance the wind velocity.

Concerning the difference in block orientation in between the "high density - high rise" block configurations, in accordance with the graphs for $V > 2$ m/s and $V = 1$-2 m/s in Fig. 7, block no. 80 has better urban ventilation than block no. 65 since the value in column no. 5 is greater than that in column no. 4. The orientation of block no. 80 is quite parallel to the main wind direction blow from the south to the north while the orientation of block no. 65 rather deviates from the main wind direction blow according to the details of morphological properties of different blocks shown in Fig. 4.

In between the "high density - low rise" block configurations, block no. 26 has better urban ventilation than block no. 30, in accordance with the graphs for $V > 2$ m/s and $V = 1$-2 m/s in Fig. 7, the value in column no. 2 is greater than that in column no. 1. The orientation of block no. 26 is quite parallel to the main wind direction blow from the south to the north while the orientation of block no. 30 rather deviates from the main wind direction blow according to the morphological properties of different blocks shown in Fig. 5.

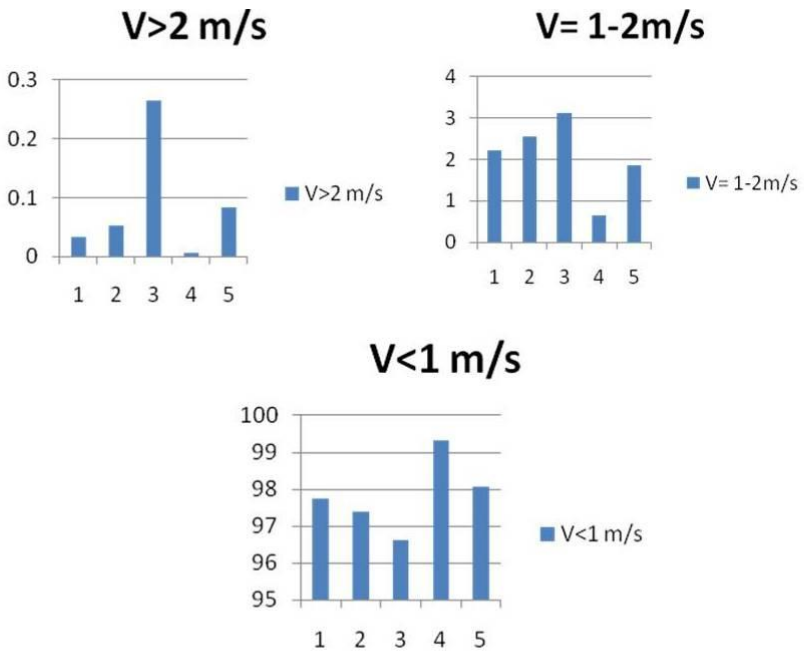


Fig. 7. Comparison of flow simulation graphs of the velocity at 1.5-meter height above ground for 5 urban block types.

The graphs for $V > 2$ m/s, $V = 1\text{-}2$ m/s, and $V < 1$ m/s (Fig. 7) show that the "high density - low rise" block type (block no. 26 and 30) has better urban ventilation than the "high density - high rise" block type (block no. 17, 65 and 80), the wind velocity range is mostly 1-2 m/s.

In the graph for $V > 2$ m/s, block no. 17 has the largest volume of velocity elements at velocity higher than 2 m/s (in per cent, compared to the total urban volume boundary) followed by block no. 80, 30, 26 and 65, respectively.

In the graph for $V = 1\text{-}2$ m/s, block no. 17 has the largest volume of velocity elements at velocity 1-2 m/s (in per cent, compared to the total urban volume boundary) followed by block no. 30, 26, 80 and 65, respectively.

In the graph for $V < 1$ m/s, block no. 65 has the largest volume of velocity elements at velocity less than 1 m/s (in per cent, compared to the total urban volume boundary) followed by, block no. 80, 26, 30 and 17, respectively. It means that the "high density - high rise" block type (block no. 17, 65 and 80) has lower wind speed than the "high density - low rise" block type (block no. 26 and 30).

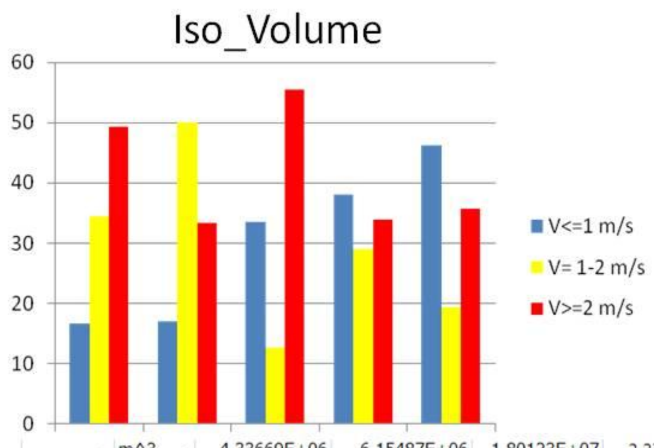
In the graphs for $V > 2$ m/s, $V = 1\text{-}2$ m/s, and $V < 1$ m/s (Fig. 7), block no. 65 ("high density - high rise" block type with deviating-from-prevailing-wind orientation) has the worst urban ventilation with very low wind speed, mostly less than 1 m/s.

9.3 Isovolume Graphs for $V > 2$ m/s, $V = 1\text{-}2$ m/s and $V < 1$ m/s

In the isovolume graph (Fig. 8) for $V < 1$ m/s (shown in blue in the bar graph), block no. 80 has the largest amount of velocity isovolume, followed by block no. 65, 17, 30 and 26, and the percentage of volume per total domain boundary is 46.3138%, 38.1104%, 33.4521%, 17.033% and 16.5869%, respectively.

In the isovolume graph (Fig. 8) for $V = 1\text{-}2$ m/s (shown in yellow in the bar graph), block no. 30 has the largest amount of velocity isovolume, followed by block no. 30, 26, 65, 80 and 17, and the percentage of volume per total domain boundary is 50.0149%, 34.4897%, 28.9047%, 19.3129% and 12.6303%, respectively.

In the isovolume graph (Fig. 8), for $V > 2$ m/s (shown in red in the bar graph), block no. 17 has the largest amount of velocity isovolume, followed by block no. 26, 30, 80 and 65, and the percentage of volume per total domain boundary is 55.4298%, 49.2811%, 35.6479%, 33.8427% and 33.2767%, respectively.



100	Isovolume v<1m/s	m^3	4.33669E+06	6.15487E+06	1.80123E+07	2.37911E+07	2.52790E+07
101	Percentage volume/fluid subdomain	%	16.58688177	17.03289313	33.45213112	38.11039489	46.31388794
102	Isovolume 1<v<2m/s	m^3	9.01743E+06	1.8073E+07	6.80079E+06	1.80443E+07	1.05414E+07
103	Percentage volume/fluid subdomain	%	34.48967883	50.01494388	12.63030922	28.90473322	19.3129957
104	Isovolume 2m/s<v	m^3	1.28847E+07	1.20246E+07	2.98462E+07	2.11269E+07	1.94573E+07
105	Percentage volume/fluid subdomain	%	49.28113275	33.27669419	55.42984493	33.84267654	35.64789793

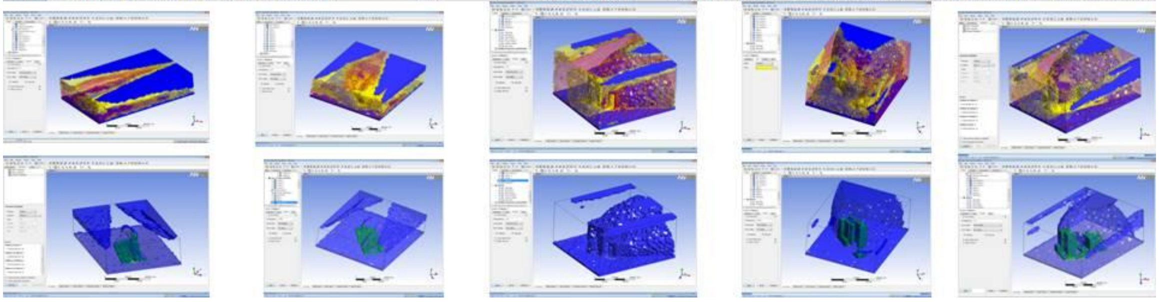


Fig. 8. Graph comparison of wind velocity isovolumes for 5 urban block types.

10. Urban Ventilation Efficiency Calculation

The bar graph in Fig. 8 shows data for three velocity ranges, the first one is for for $V <$ 1 m/s, the second one is for V = 1-2 m/s, and the third one is for $V >$ 2 m/s. The following results are obtained after weighting the urban ventilation efficiency: block no. 26 has the best urban ventilation, followed by block no. 17, 30, 65 and 80 and the calculated values are 233.38, 225, 216.86, 197.43 and 191.85, respectively.

The results presented in this section show major differences between the five urban block types:

- The “high density - low rise” block type with parallel-to-prevailing-wind orientation (block no. 26) has the best urban ventilation efficiency: wind velocity greater than 2 m/s for 49.28%; wind velocity between 1 to 2 m/s for 34.49%; and wind velocity less than 1 m/s for 16.58% of the cases.

- The “high density - high rise” block type with a single, large and tall building (block no. 17) can catch the wind and enhance the wind speed: wind velocity greater than 2 m/s for 55.43%; wind velocity between 1 to 2 m/s for 12.63%, and wind velocity less than 1 m/s for 33.45% of the cases.

- The “high density - low rise” block type with deviating-from-prevailing-wind orientation (block no. 30) has: wind velocity greater than 2 m/s for 33.28%; wind velocity between 1 to 2 m/s for 50.01%; and wind velocity less than 1 m/s for 17.03% of the cases.

- The “high density - high rise” block type with parallel-to-prevailing-wind orientation (block no. 80) has: wind velocity greater than 2 m/s for 33.84%; wind velocity between 1 to 2 m/s for 28.90%; and wind velocity less than 1 m/s for 38.11% of the cases.

- The “high density - high rise” block type with deviating-from-prevailing-wind orientation (block no. 65) has: wind velocity greater than 2 m/s for 35.65%; wind velocity between 1 to 2 m/s for 19.31%; and wind velocity less than 1 m/s for 46.31% of the cases.

11. Conclusion

Considerable effort has been made in recent years to improve the scientific understanding of airflow phenomena governing urban ventilation. This study was focused on the morphological properties of urban block types to determine which urban block type has bigger impact on urban ventilation efficiency. Actually, the urban ventilation varies mainly due to the presence of buildings, wind vortices, low-pressure areas and channeling effects to air-stagnant-zone (zero wind velocity) hotspots. For example, stagnant zones have been often observed on the leeward side of buildings under perpendicular wind conditions.

CFD is a numerical modeling technique that can be applied to many different fields of engineering and scientific research. As far as urban ventilation is concerned, the main advantage of the method is that it can reproduce the entire flow and concentration fields within urban areas of any configuration. Although limited by the representation of real building geometry and processes, the two-dimensional CFD-based models allowed fast airflow simulation of urban ventilation. The comparison of five urban block types revealed that the “high density - low rise” type with parallel-to-prevailing-wind orientation has the best urban ventilation efficiency.

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