# INVESTIGATION OF THE VENTILATION RATE AROUND DIFFERENT URBAN MORPHOLOGICAL PROPERTY TYPES: HIGH RISE -VS- LOW RISE IN BANGKOK'S HIGH DENSITY AREAS

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## Abstract

As a consequence of city development and increased urbanization, Bangkok, the capital of Thailand, has experienced serious air pollution problems in high density areas over the past several decades, especially at pedestrian-level (at 1.5 meter level above ground) between groups of buildings in the city's central block. As we all know that urban settings have a direct impact on the urban air flow. Lack of research because urban morphology (Greek morph̆ : shape) is too complicated to do air flow simulation. The objective of this study is to find the relationship between urban high-rise and low-rise morphology properties and urban air ventilation in high density areas of Inner Bangkok. The methodology involves an investigation using computer fluid dynamics (CFD) simulation. The results based on air change rate. Main findings of this paper are as follows; Urban high rise- high density areas has better ventilation rates than low rise- high density areas in all cases. The ventilation rate from high to low are as followings, 1) urban high rise- high density are block number 80, 17 and 65 and ACH is 26.23646, 25.63358, 12.77694 2) urban low-rise- high density are blocks 24, 30 and 26 and ACH is 11.72196, 11.19111, 5.769723, respectively. The conclusion of this research is the most influential variable factors is the height of the building. Blog orientation and open space in the city block.

**Keywords:** Urban Morphological Properties, Urban Ventilation, The Intensely Developed Areas, Inner Bangkok

## บทคัดย่อ

ผลมาจากการพัฒนาเมืองและการเจริญเติบโตของเมืองที่เพิ่มขึ้นกรุงเทพมหานคร เมืองหลวงของประเทศไทยได้ประสบปัญหามลพิษทางอากาศที่รุนแรงในพื้นที่ที่มีความหนาแน่นสูงในช่วงหลาย

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ทศวรรษ ที่ผ่านมาโดยเฉพาะอย่างยิ่งที่คนเดินเท้าในระดับ (ที่ระดับ 1.5 เมตรเหนือพื้นดิน) ท่ามกลางกลุ่มอาคารในบล็อกถนนใจกลางเมือง เป็นที่รู้กันดีว่าการจัดวางอาคารในเมืองมีผลกระทบโดยตรงต่อการไหลของอากาศในเมือง ยังคงขาดการศึกษาในเรื่องนี้เพราะสัณฐานเมือง (Morphe ภาษากรีกแปลว่า รูปทรง) มีความซับซ้อนสูงเกินกว่าที่จะการจำลองการไหลของอากาศผ่านเมือง วัตถุประสงค์ของการศึกษานี้คือการหาและความสัมพันธ์คุณสมบัติลักษณะทางสัณฐานวิทยาในเมืองและการระบายอากาศในเมืองในพื้นที่ที่มีความหนาแน่นสูงของภายในกรุงเทพฯ โดยเปรียบเทียบระหว่างอาคารสูง-แน่น และอาคารเตี้ย-แน่น วิธีการที่เกี่ยวข้องกับการตรวจสอบการใช้คอมพิวเตอร์พลศาสตร์ของไหล (CFD) การจำลอง ผลการศึกษาวัดจากค่าอัตราการเปลี่ยนแปลงของอากาศ (Air Change Rate: ACH) ข้อค้นพบของการวิจัยมีดังนี้ คือ 1) พื้นที่เมืองแบบอาคารสูง-แน่นมีอัตราการระบายอากาศดีกว่าพื้นที่เมืองแบบอาคารเตี้ย-แน่นทั้งหมด ผลอัตราการระบายอากาศเมืองเรียงจากสูงไปต่ำได้ดังนี้ พื้นที่เมืองแบบอาคารสูง-แน่น คือ บล็อกที่ 80, 17 และ 65 มีค่า ACH คือ 26.23646, 25.63358, 12.77694 รองลงมาคือ 2) พื้นที่เมืองแบบอาคารเตี้ย-แน่น คือ บล็อกที่ 24, 30 และ 26 มีค่า ACH คือ 11.72196, 11.19111, 5.769723 ตามลำดับ ผลสรุปของการวิจัยนี้ คือ ปัจจัยตัวแปรที่มีอิทธิพลมากที่สุด คือ ความสูงของอาคาร การวางทิศทางของบล็อก และขนาดพื้นที่เปิดโล่งในบล็อกถนน

## INTRODUCTION

Urban ventilation directly influences the cities' inhabitants' health and well-being. (Kuttler, 2004). The link between the humanly constructed environment and people's physical and psychological health are rooted in 19th century industrial cities. Unsanitary and overcrowded slum conditions facilitated the transmission of airborne 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 about "urban ventilation". These changes highlight common interest in the impact of humanly-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 serious urban air environment problems. The cause of rapidly growing metropolitan infrastructures is increasing the urban surfaces' roughness, which obstructs urban wind speeds. Working on a better understanding and dealing with the urban air ventilation issue has progressed significantly. The most critical problem is found in the densest and the most congested urban areas. This problem highlights the importance of urban redevelopment designs that make possible the linkage between public health, urban planning, and the exploration of strategies for collaborating on tangible actions for healthier cities. Thus, this is an urgent problem and a challenge to systematically evaluate urban ventilation performance.

It is a fact that urban microclimates (including urban ventilation) can be improved, worsened, or mitigated by urban planning (Gehrenbach et al., 2006; G'omez et al., 2006). Due to inconsiderate urban plan inhabitants can suffer from inadequate ventilation. Currently, many urban planning researchers have focused their studies on urban ventilation by measuring ventilation efficiency within urban domains. Mostly urban climate models have developed a method for inventorying the physical characteristics of the urban environment (Ellefsen, 1990; Voogt & Oke, 1998). Therefore, urban planners need real information (on a proper scale) to address the urban micro-climate on their spatial plan by the time they reach the stage of redeveloped design. To do so, urban planners need enough accurate and reliable information on the real urban morphological characteristics that affect urban ventilation. Mostly data use is a cluster of pure cubic boxes rather than the actual district's urban morphology, therefore such data is artificial and unreliable.

## VARIABLES

The overall purpose of this paper is to present an overlaid Bangkok urban roughness mapping method that aims at studying the engineered air change rate on 6 extreme obstacle morphological urban block heterogeneity types in urban areas that can be separated to 2 urban morphological property types; High rise- high density VS Low rise- high density (see Fig.1).

To investigate urban design parameters and to evaluate how morphological property parameters in urban blocks influence urban ventilation efficiency and in order to find out key parameters for modifying and improving planning in urban areas, an effective environmental planning and man-


**Figure 1: Morphological study types "Bangkok: High rise- high density VS Low rise- high density"**

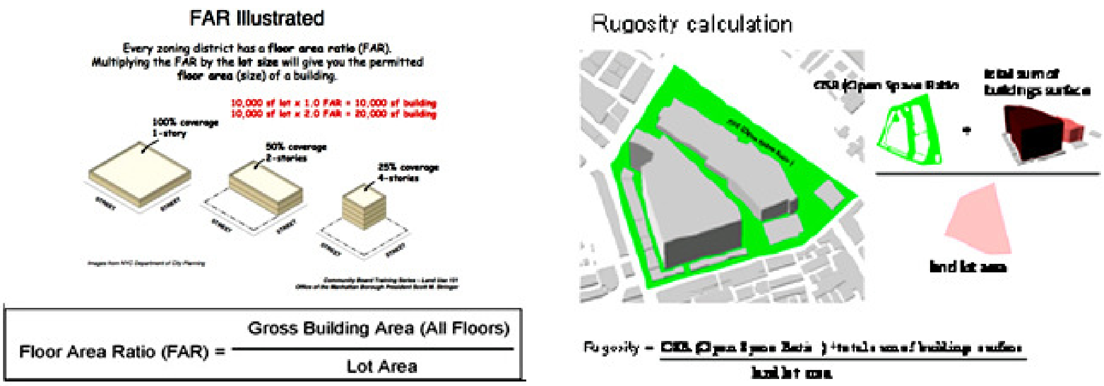



**Figure 2: Variable calculation (a) Floor area ratio (FAR) (ref: NYC city of planning, 2013) and (b) urban Rugosity (ref: Adolphe, 2001)**

agement process is needed. Such a process will help decision-makers to formulate and implement strategies to improve urban ventilation and to achieve a sustainable growth pattern.

This paper will focus on 5 urban design parameters as follows; **1) block size; 2) floor area ratio (FAR),** which is the total square feet of a building divided by the total square feet of the lot the building is located on. FAR is used by local governments in zoning codes (see Fig.2 a); **3) open space ratio (OSR),** which is the proportion of a development that is required to be left as open space. It is determined by dividing the area of the open space by the area of the base site; **4) urban rugosity** is the ratio of total skin surface area of all buildings in each city block to the area of the base site (see Fig.2b); **5) building density** is the number of buildings by the base site. The simulation of this paper uses Bangkok's prevailing wind direction that most often blows from the south to the north.

## STUDY AREA

Bang Rak district is Bangkok's Central Business District (CBD) or downtown. It contains the maximum number of tall buildings. This complex urban topography strongly affects air quality spatial pattern as determined by the wind regimes and how they interact with the urban topography they flow through (USEPA, 2010).

This paper uses the Bang Rak city block as a unit for analysis. "City block" is an area in a city surrounded by streets and usually containing several buildings. From this study, Bang Rak district is contained within 98 city blocks (see Fig.3). The average block size is approximately 30,000-45,000 square meters. By this data, it has the obvious typical similar high density urban block arrangement characters that can be seen in many Bangkok regions.

## METHODOLOGY

Flow in a densely built-up urban area is complex because of the influence of buildings on the flow and dispersion of air

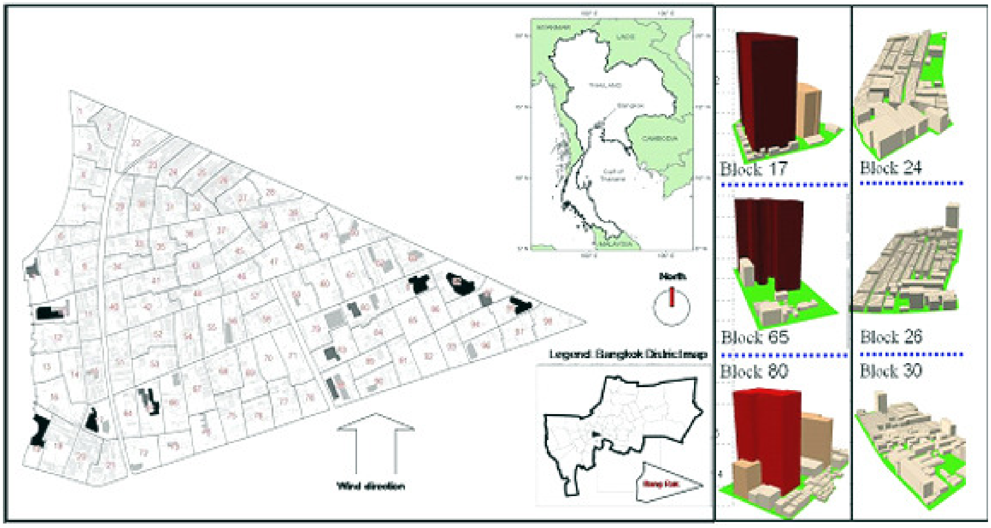



**Figure 3: Study area: 98 City blocks of Bang Rak District, the average block size is approximately 30,000-45,000 square meters and the urban morphological property type is both "high rise- high density" and "low rise -high density"**

and unsteady meteorological conditions. To understand the fluid dynamics of such complex flow and dispersion and to better predict them, urban flow and dispersion have been extensively studied through Computer fluid dynamics (CFD) model simulation (Blocken et al.2008). With advances in numerical modeling and the rapid increase in computing power, CFD models are now capable of simulating or predicting flow in a real urban setting with a large computational domain and high horizontal and vertical resolutions. In this situation, appropriate boundary conditions and urban building configuration data should be given for realistic simulation or prediction.

Looking at urban building configuration data (by getting official GIS buildings map information data from Bangkok Metropolitan Administration: BMA, 2006) is one approach that can analyze these developments quantitatively with respect to spatial flow changes in actual scale. CFD were used to build a mathematical representation and numerically solve the governing equations, the Navier-Stokes equations model equations over a discretized flow field based on a finite volume method was used. This approach was used because it allows a wide range of applications such as irregular geometries, turbulent airflow, and open flow inlets and outlets. Up to the present time, the study of urban block form has been limited to a group of a few pure cubic boxes rather than in real districts of actual urban blocks with real meteorological wind data input. A group of pure cubic boxes does not provide enough information for actual evaluation. The CFD technique with a standard k-ε turbulence model was used for more accurate evaluation. The program was able to verify this by using a new mathematical formula, the first of its kind, to simulate the long-term random motion of pollutant particles as would be found in the real world. These more realistic simulations revealed that coherent patterns emerged from the random motions of particles carried along by the urban flow. A real urban block model of a typical district existing in the intensely developed area of inner Bangkok was adopted as the 5 reference cases for the simulation with the varied urban parameters as mentioned above.

## PROJECT SET UP AND DATA PRE-PROCESSING

Overall data and Method analysis are separated into 2 parts; 1). GIS pre-processing data 2). Computer fluid dynamics (CFD) simulation processing.

For better understanding of the influencing factors of terrain features and urban built form structures on the wind field and urban ventilation, the determination is based on topographic information and surface properties derived from a digital terrain model and from the Bangkok Metropolitan Administration's block map data. "Friction force" is the key answer. In this case, the friction force of the earth's surface in an urban setting is known as "surface roughness" (see Fig.4 b)

**1. GIS pre-processing:**

A Geographic Information System (GIS) is a data set of urban roughness blocks transferred to an Auto-CAD file to use as a base map (see Fig.3) The first step is taking different key variable maps of the same area and overlaying them, one on top of the other, to form a new map layer. For this paper, in urban planning, the Potential Surface Analysis (PSA) technique is widely used for analysis. This method requires an appropriate ranking for weighting the PSA's factor based on the physical data of the studied area. The overlay factor mapping details are as follows; 1) administrative boundaries 2) built environment. However, PSA is a complex analytical technique and uses a variety of parameters for calculating. Geographic Information System (GIS) plays an important role in analyzing and thus increases the accuracy of weight of each parameter in the PSA approach.

The second step is using a Digital Terrain Model (DTM) to continue the representation of a ground surface landform which is commonly used to produce a topographic map--with the Potential Surface Analysis (PSA) technique. Analysis is divided into 2 parts; Part 1). administrative

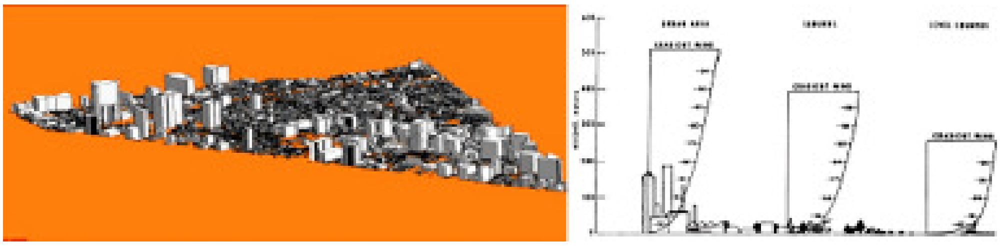


**Figure 4: Left (a): GIS data of urban roughness block transferred into an Auto-CAD file to use as a CFD simulation base map. Right (b),** ***A vertical wind profile*** **of different terrain friction roughnesses.**

boundaries, the selected data focuses on weighing 3 variables; a) floor area ratio (FAR) b) open space ratio (OSR) c) ratio of total skin surface area of the urban block to the lot area (urban rugosity). And Part 2) built environment, the selected data focuses on weighing 3 variables; a) total usable area b) the number of buildings per block lot (building density) and c) building surface roughness. (see Fig.4).

Using both steps data overlay mapping on GIS auto cad base map. (see Fig.5)

## 2. Unit of Analysis Study

As per the overall site analysis is given an outstanding typical high density urban block characterization.

And a result of GIS pre-processing can be categorized into 2 types, as follows; 1) The first type is "high rise- high density" (Fig.6a) and the second type is "low rise-high density" (see Fig.6b).

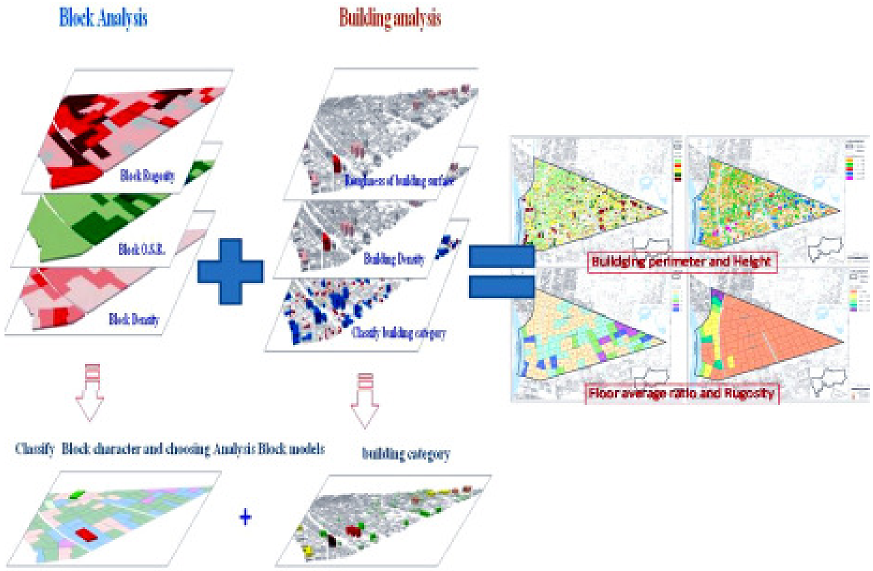
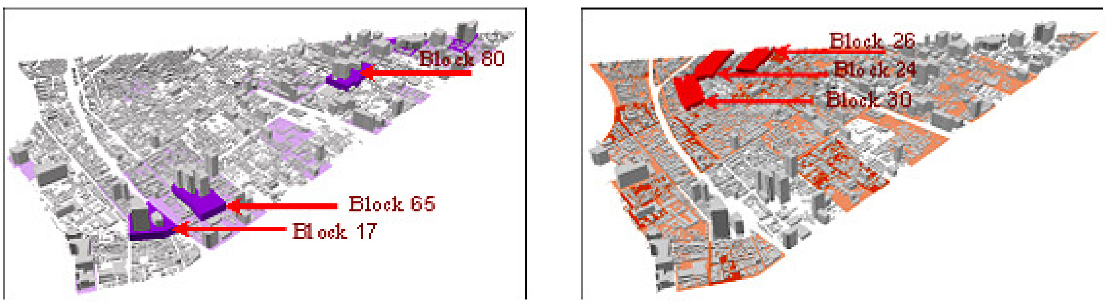



**Figure 5: The Digital Terrain Model (DTM) overlay process on a GIS map and variables mapping**




**Type A:** "high rise- high density" **Type B:** "low rise -high density"

**Figure 6: An Urban Morphological Property Block**

2.1. *Analysis of the first unit type: high rise -high density;*

By analyzing all GIS pre-processing data, the result shows the top three highest densities of the "high rise- high density" type is found in block nos. 17, 65, 80; details as follows (see Fig.7);

2.1.1. ***Urban morphology property characteristics of Block no.17***

The block's area is 33,942.94 square meters, the floor area ratio (FAR) is 16, the open space ratio (OSR) is 0.0003, the total building surface (Rugosity) is 4.41, the building surface roughness is 1,326,190 square meters. The number of buildings per block lot (building density) comprised 53 buildings with 3 extremely large building clusters, including one with 63-storeys. The Silom Precious Building has a total building surface of 670,867 square meters. The 30-storey and 10-storey Lert Sin Hospital Building buildings have a total surface of 270,851 square meters and 113,235 square meters respectively. The rest of the buildings have an average building surface of from 273 to 2974 square meters each. The average building height is 1-5 storeys.

2.1.2 ***Urban morphology property characteristics of Block no.65***

The block area is 43,771.91 square meters, the floor area ratio (FAR) is 12, the open space ratio (OSR) is 0.0005, the total building surface (Rugosity) is 4.58, the building surface roughness is 875,856 square meters, the number of buildings per block lot (building density) is comprised of 56 buildings with 2 large building clusters and 3 extremely large building clusters, such as the 56-storey and 14- storey Holiday Inn Crown Plaza Building, with a total building surface of 540,178 and 150,257 square meters respectively, the 56-

| 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 | 1,326,190.00 | 875,856.23 | 606,909.14 |
| BUILDING STOREY | 63 | 56 | 50 |

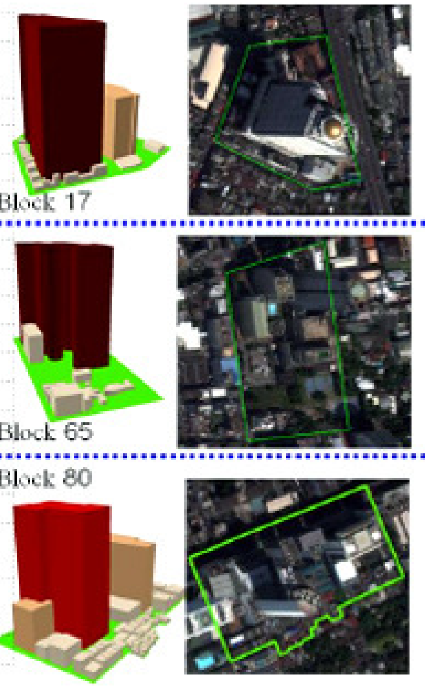



**Figure 7: Urban morphology property characteristics "high rise- high density" type of Block no. 17, 65, 80**

storey Silom Galleria Building has a total building surface of 875,856 square meters. The rest has an average building surface of from 101 to 5,572 square meters. And the average building height is 1-5 storeys.

2.1.3. ***Urban morphology property characteristics of Block no.80***

The block area is 42,574.92 square meters, the floor area ratio (FAR) is 10, the open space ratio (OSR) is 0.0007, the total building surface (Rugosity) is 4.28, the building surface roughness is 696,909 square meters, the number of buildings per block lot (building density) is comprised of 111 buildings with 2 large building clusters, such as the 50-storey United Building, with a total building surface of 560,190 square meters, the 30-storey CP Tower Building, with a total building surface of 339,946 square meters and the Liberty Square tower with 174,901 square meters respectively. The rest of the buildings have the average building surface of from 172 to 7,945 square meters. And the average building height is 1-5 storeys.

2.2. *Analysis of the second unit type: low rise -high density;*

By analyzing all GIS pre-processing data, the result shows the top three highest densities of the "high rise- high density" type is block nos. 24, 26, 34; details as follows (see Fig.8);

2.2.1. ***Urban morphology property characteristics of Block no.24***

The block area is 36,931.34 square meters, the floor area ratio (FAR) is 2, the open space ratio (OSR) is 5, the total building surface (Rugosity) is 4.82, the building surface roughness is 22,440.31 square meters, the number of buildings per block lot (building density) is comprised of 350 buildings, 2 large building clusters, such as the 6-storey PS House Apartment Build-

| BLOCK PER BUILDING | Block 24 | Block 26 | Block 30 |
|---|---|---|---|
| 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 | 3.33 | 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 |

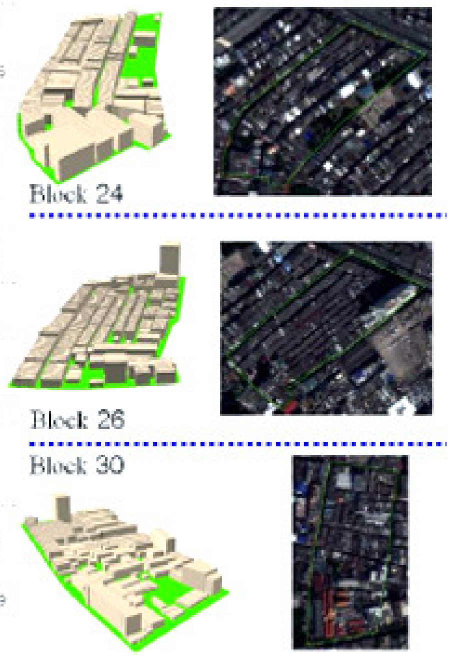



**Figure 8: Urban morphology property characteristics "low rise -high density" type of Block no. 24, 26, 30**

ing and a 3-5 storey Shop house. The rest has an average building surface of from 166 to 6,795 square meters. And the average building height is 1-5 storeys.

2.2.2. ***Urban morphology property characteristics of Block no.26***

The block area is 31,601.72 square meters, the floor area ratio (FAR) is 1, the open space ratio (OSR) is 3, the total building surface (Rugosity) is 4.24, the building surface roughness is 35,976.03 square meters, the number of buildings per block lot (building density) is comprised of 439 buildings, 1 large building cluster, including the 6-storey CSP Mansion building which has a surface of 11,560 square meters, and 1 extremely large building cluster, the 15-storey Thai-Shinnawatra Building. Most buildings in this block are 3-5 -storey Shop houses. The rest have an average building surface of from 155 to 2,016 square meters. And the average building height is 1-5 storeys.

2.2.3. ***Urban morphology property characteristics of Block no.30***

The block area is 23,553 square meters, the floor area ratio (FAR) is 1, the open space ratio (OSR) is 6, the total building surface (Rugosity) is 3.89, the building surface roughness is 35,971.03 square meters, the number of buildings per block lot (building density) is comprised of 415 buildings, including 4 large building clusters, such as the 13-storey Pramuan Apartment building with a surface of 23,553 square meters and the 6-storey Police Residence with a surface area of 17,220 square meters. The rest of the building in this block have the average building surface of from 132 to 4,629 square meters. Most buildings are 3-5-storey Shop houses, and the average building height is 1-5 storeys.

This step is making an "**analysis mode**l" by choosing from the outstanding examples of the urban morphology property characteristics; the chosen blocks of "high rise- high density" are Blocks no. 17, 65, 80 and those chosen from the "low rise-high density" are Blocks no. 24, 26, 30. The CFD simulation processing step comes next.

## CFD SIMULATION PROCESSING

### 1. CFD Data input

Normally air flow behavior follows a turbulence Flow pattern. The equation to solve a turbulence problem is a very complicated non-linear equation called "Navier-Stoke". To find the answer to this equation requires a parallel-calculation supercomputer system. This paper is based on measurements undertaken in the intensely developed urbanized area by using the Fluent 5.6 CFD. It was simulated on all 5 analysis block models (block no.17, 65, 80, 26, 30) with the same input conditions, including the following details: wind Inlet-velocity input was 2 m/s, the pressure was set to zero Pascal (Pa) at the free outlet open to the atmosphere. Wind outlet pressure setting was: Outlet Back, Outlet Right, Outlet Left, and Outlet Roof = 0 Pascal. For all 5 analysis block models, the computational boundary domain size was approximately 10 times the size of the study object.

The details of the CFD analysis process steps are as follows; 1) Problem statement 2) Mathematical model 3) Mesh generation nodes/cells 4) Space discretization 5) Time discretization algebraic system 6) discrete Iterative solver 7) CFD software implementation 8) Simulation run parameters 9) Post processing visualization 10) analysis of data 11) model verification / validation / adjustment.

**2. CFD framework:**

Using basic principles of the flow of liquid and particles, these principles of air flow are governed by the basic physical laws of the conservation of mass, momentum, and energy. The conservation laws are expressed mathematically by means of balanced differential equations, which describe the flow process under general conditions in an infinitesimal control volume. SIMPLER equations are obtained by implementing the specific flow conditions characteristic of a chosen control volume. The energy balance conservation law states that the mass flow inlet is equal to mass flow outlet. The design and construction of a quality grid is crucial to the success of the CFD analysis. For this paper, the choice of an appropriate grid type depends on: Geometric complexity, the Flow Field and Cell, and element types supported by the solver. Meshing is designated as the grid cells or elements on which the flow is solved. Simulation result validation was measured by using Plots Check to check the model assumptions and using a residuals plot to check the convergence. For this study, the Mesh setting used was 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 converged after about 2 hours and approximately 1,000 iterations using a computer with eight 2.66 GHz processors and 3.25 GB of RAM.

## MEASUREMENT

In summarizing the main 4 steps for CFD measurement, which are 1) using 2-dimensional CFD-based parametric analysis of a model of airflow patterns, and 2) using a contour plot for overall flow observation. The cutting plane height is 1.5 meters above ground level (this level has the most impact on pedestrians and urban inhabitants), 3) CFD simulation data results are able to show all Velocity and Pressure points, especially at on the inlet and out flow planes. The flow results can be seen clearly on both the top and side views. It can be categorized by using a velocity zone, such as a high or low velocity zone. These results can be used to investigate which morphology block types produce the worst flow by observing the velocity loss at each city block built form. And 4) the final step is using a 3-dimensional CFD-based parametric to investigate main key factors affecting urban ventilation.

For this paper, the key results were measured by **air change rate (ACH)**. The definition of CFD air change rate (ACH) is generally used as a way to measure the dilution ventilation rate. Air exchange rate means replacing the entire volume of air in the breathing zone in one minute or one hour. The following formula can be used to determine the air exchange rate: Number of air changes per hour = Outside air intake rate X 60 per whole space volume. Air change rate (ACH) or air change effectiveness (ACE) is determined in accordance with ASHRAE Standard 129.

## RESULT

1. The whole- Bang Rak -district CFD flow pattern with air velocity level legend is as follows;

Generally, wind blows from south to north (see Fig.9). The legend index of wind velocity color range is blue to red. The velocity ranges start from 0 to 1.630 meters per hour. Higher speed wind flows through wide streets (red color). Wind cannot flow inside the high density blocks (green and blue color). The southern part of Bang Rak district (Silom and Sathon road) has a lot of high rise buildings. The northern part of the district (Si Praya road) has a lot of low rise buildings.

2. The comparison of flow simulation among 6 urban morphology property characteristics types, Air change rate (ACH) measurement result is as follows;

**Table 1: Air Change Rate (ACH) Measurement Results**

| low rise -high density | | low rise -high density | |
|---|---|---|---|
| block no. | ACH | block no. | ACH |
| 24 | 11.72196 | 17 | 25.63358 |
| 26 | 5.769723 | 65 | 12.77694 |
| 30 | 11.19111 | 80 | 26.23646 |

The result shows the top three highest densities of "high rise- high density" type are block nos. 17, 65, 80 which have better ventilation efficiency (air change rate) than the top three highest densities of "low rise- high density" type which are block nos. 24, 26, 34; the ACH values the selected blocks are 25.63358, 12.77694, 26.23646, 11.72196, 5.769723, and 11.19111 respectively. (Graph 1)

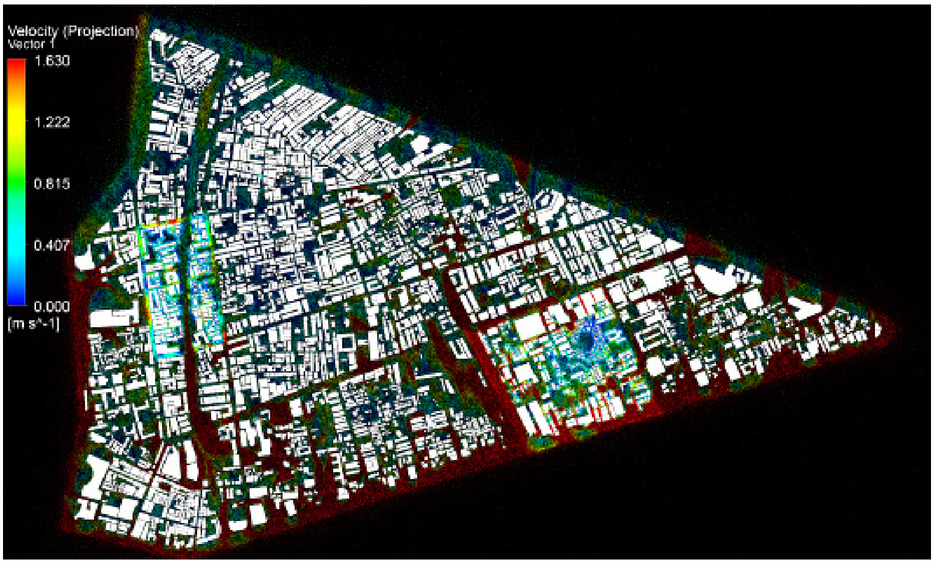



**Figure 9: The whole district CFD flow pattern with air velocity level legend**

ASHRAE Standard 129 suggests that the ACH figure should be 0.95 or greater to pass the requirements. All our study blocks had ACH figures greater than 1, so all study blocks pass the ASHRAE Standard.

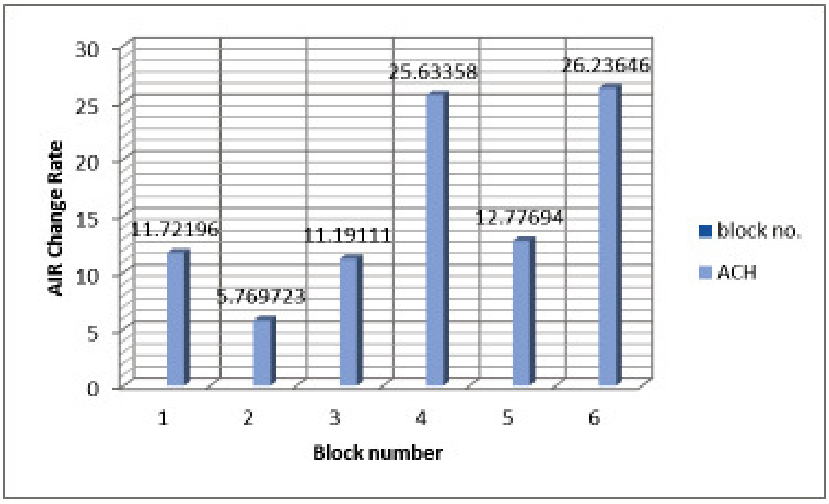
3. High rise-high density Analysis;

3.1. The best ACH block of high rise-high density is block no.80. The second best ACH is found in block no.17. Details of the velocity vectors and the speed levels of the high rise-high density blocks are as follows (Fig.10);

3.2. Block no.80 has the best ACH because the block orientation produces cross-ventilation with the prevailing wind direction.

3.3. Block no.17 has good ACH because the location of the block is close to a big street which acts as a wind source.

3.4. Block no.65 has lower ACH because the block location is surrounded with other blocks. Wind cannot flow past




**Graph 1: Air Change Rate (ACH) Measurement R esults**

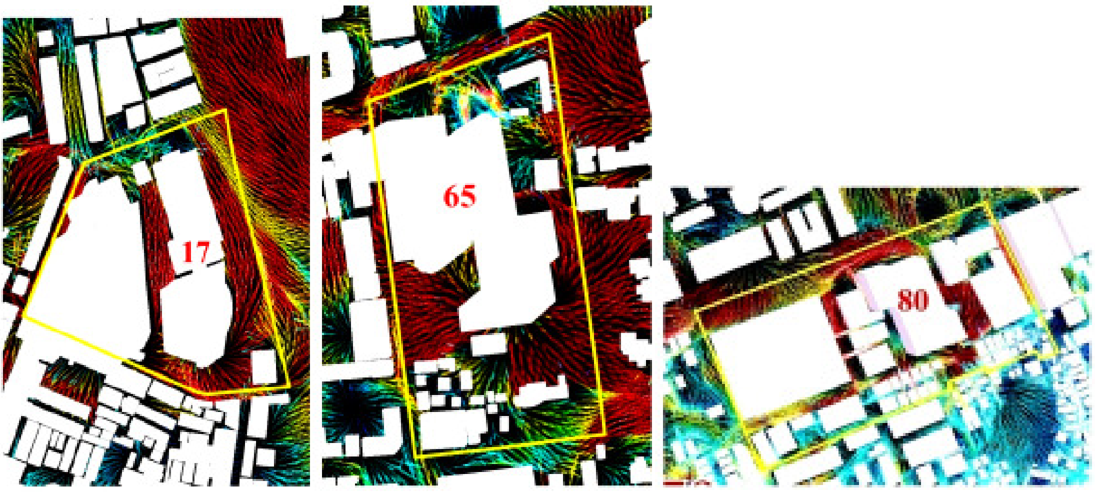



**Figure 10: Details of velocity vectors and speed level of high rise-high density block no.17, 65, 80**

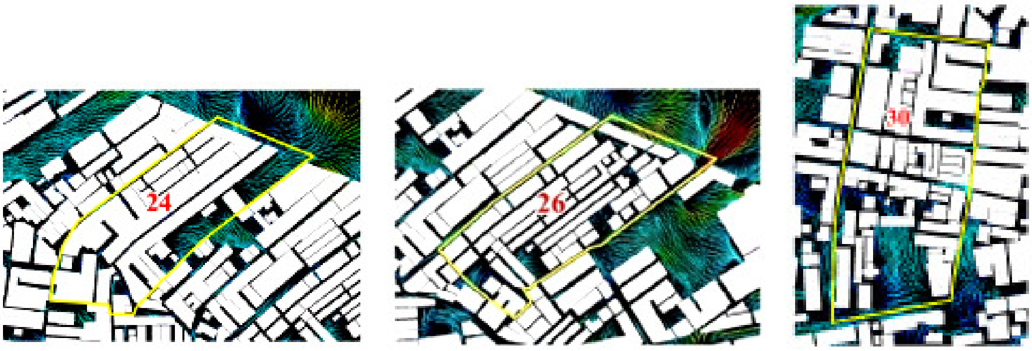



**Figure 11: Details of velocity vectors and speed level of high rise-high density blocks no.24, 26, 30**

the large buildings which act as massive obstructions to the flow of the wind inside the block itself.

4. Low rise-high density Analysis;

The best ACH block of the low rise-high density type is block no. 24. The second best ACH is block no.30. Details of the velocity vectors and the speed levels of the high rise-high density blocks are as follows (Fig.11);

4.1. Block no.24 has the best ACH because the location of the block is close to the street which acts as a wind source. This block has more open space.

4.2. Block no.30 has good ACH because the block's orientation is parallel with the prevailing wind direction. This block also has less open space.

4.3. Block no.26 has lower ACH because the block's location is surrounded by other blocks. Wind cannot flow past the block.

5. The correlation of all 5 urban design parameters (1) block size; 2) floor area ratio (FAR); 3) open space ratio (OSR); 4) urban rugosity are as follows: (Table 2-4)

From table 3, density and FAR is the most significant factors to urban ventilation.

**Table 2: Descriptive Statistics of All Variables**

| Block No. | ACH | far | osr | blocksize | density | rugosity |
|---|---|---|---|---|---|---|
| 24 | 25.63358 | 14.88 | 55.03 | 33943.12 | 0.001561 | 4.41 |
| 26 | 11.72196 | 2.3 | 63.62 | 36931.37 | 0.009477 | 4.83 |
| 30 | 5.769723 | 1.84 | 53.38 | 31618.91 | 0.013947 | 4.25 |
| 17 | 11.19111 | 1.85 | 63.36 | 41320.43 | 0.010043 | 3.9 |
| 65 | 12.77694 | 12.06 | 47.01 | 43771.92 | 0.001279 | 4.58 |
| 80 | 26.23646 | 10.57 | 59.64 | 45202.26 | 0.001637 | 4.29 |

**Table 3: Correlation of All 5 urban Design Parameters**

| | | ACH | far | osr | blocksize | density | rugosity |
|---|---|---|---|---|---|---|---|
| ACH | Pearson Correlation | 1 | .782 | .127 | .312 | -.807 | .032 |
| | Sig. (2-tailed) | | .066 | .839 | .547 | .052 | .952 |
| | N | 6 | 6 | 5 | 6 | 6 | 6 |

**Table 4: Multiple Regression Coefficients of All 5 Urban Design Parameters**

| Model | B |
|---|---|
| (Constant) | 151.364 |
| far | -1.912 |
| osr | .625 |
| blaocksize | -.001 |
| density | -3999.236 |
| rugosity | -19.832 |

6. Summarized formulation finding from this paper is as follows:

ACH = 151.364 - 1.912FAR* + .625 OSR -0.001 block size -3999.236 density* -19.832 rugosity

Noted: From table 4, the variable ACH is directly proportional to the variable OSR and the variable ACH inversely proportional to the variable FAR, block size, density and rugosity.

## DISCUSSION

The "High rise- high density" block type has much better ventilation efficiency than "low rise- high density". People have better options when they select a high density urban zone to live in. This paper recommends choosing a "high rise- high density" area.

The factors that have the most impact are density and FAR. This means we need to look at density, block arrangement, FAR, and building height, which are all inter-related with each other. We find that tall buildings have a special impact on wind flow pattern and ventilation efficiency. For example, in this paper, if we have a particularly tall building that sticks out above the surrounding roof-level (urban canopy layer), the oncoming wind impacts the windward face of the tall building and produces a stagnation point in the center at about 3/4 of the building height (Oke, 1987). The rest streams down the windward face of the building to the ground. As a result of downward wind stream from the tall building, wind flow to the rest of the buildings in the urban block is enhanced because wind speed at higher levels is much faster than at lower levels (see Fig.12).

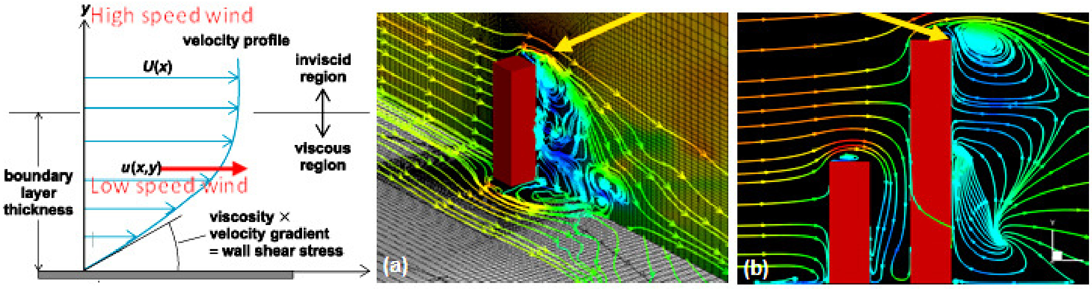



**Figure 12: Wind flow around high-rise buildings: (a) velocity streamlines around a single building and (b) flow field around adjacent mid- and high-rise buildings (Source: Dagnew and Bitsuamalk, 2012)**

If the distance between buildings is appropriate, the aerodynamic areas of each building act individually and the impact of tall buildings on wind flow is positive. But if the distance between buildings is not large enough, negative aerodynamics come into effect, such that whatever set is denser and more compact, the behaviors of the wind flow and the impact on the speed require more complex analysis and negative effects apparently occur (Masoud, 1997).

## CONCLUSION

Considerable efforts have been made in recent years to improve the scientific understanding of airflow phenomena governing urban ventilation. This paper has focused on urban morphology property characteristic types, specifically which urban block type has the larger impact on urban ventilation efficiency. Actually, urban ventilation variation is mainly due to the presence of buildings, wind vortices, low-pressure areas, and the channeling effects of 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.

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. The final conclusion is that, in a comparison among 6 urban morphology property characteristic types, the "high density-low rise morphology property characteristic type with tall buildings in the middle and with a cross-prevailing-wind orientation" has the best urban ventilation efficiency.

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