Urban Ventilation, Improving the Wind Environment in High Density Cities by Understanding the Urban Morphology

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Abstract
There is clear evidence that Heat island has changed cities microclimate from their original and it has led to increased overheating risk, longer summer periods and higher energy consumption for cooling. Understanding of the relation between urban morphology and favorable wind conditions could provide a key to avoid such serious episodes and to improve the cities' air quality as one the most important parameters affecting the urban life experience. Yet optimizing permeability of urban fabric to ensure adequate natural ventilation in urban areas is an unresolved issue faced by planners and architects.

In this paper a method has been introduced to analyze microclimate in urban compact patterns. Through this method are examined nine pilot samples, taken from different compact cities around the world. The results of the analysis are patterns' wind flow direction, speed and temperature that are compared among selected patterns. These kind of comparisons and analysis could be helpful not only for monitoring the existing microclimate condition for necessary interventions, but also to evaluating natural ventilation and wind comfort in further urban projects.

It is also proposed a user-friendly method to map the urban microclimate. The proposal is initiated from the fact that existing simulation software are time consuming and complex process of model preparation, simulation and results interpretation. The method is mainly made of three steps: 1) patterns recognition, 2) recognition of the main street canyons, 3) integration of patterns microclimate database with the GIS tables of data to provide wind maps.

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Introduction

Urban ventilation is in a close relation with today's most concerning issues of cities environmental management. Study of the airflow in and around buildings on one hand demonstrates the role of urban ventilation in mitigation of cost and energy consumption through both conservation and production of energy. On the other hand, it shows the influence it could have on both outdoor and indoor comfort as well as the air quality.

The question is how we can analyze or measure the effect of invisible force of the wind on the urban tissue and by understanding it how we can improve the air condition in that context.

The mission of the research was to introduce an intermediate level technique for wind analyzes to fill the gap between regional wind maps and wind simulations at district and building scale.

This technique is based on the analysis of air fluxes in compact cities build-up patterns. It proposes a way to investigate the permanent effect of build environment on the cities microclimate. A morphological kind of approach has been employed to emphasizing the effect of different urban forms and patterns on cities' ventilation and wind comfort.

Examination of the wind flow field in the actual urban context and mapping them, allows us to not only evaluate the existing urban tissue, but also, to predict the city's microclimate changes implied by the urban densification process and new urban projects. Appliance of this tool lets us examine the effect of built environment on the parameters such as wind speed, air temperature and flow direction.

What makes this technique sought-after in comparison with the existing simulation software, at the urban level, are advantages such as fast computability, user friendly, and modifiability of the maps over the time along with ever-changing cities and comparability of results obtained from several urban project.

Microclimate condition of urban patterns three-dimensional models are simulated using the Computational fluid dynamic method. A method in which Computers are used to perform the calculations required to simulate the interaction of liquids and gases with surfaces. In each simulation it is involved a comprehensive set of environmental indicators describing the climate of the site, characteristic of the wind inflow and sun light.

MATLAB software is the other tool used in this research in order to figure out the morphological properties of each pattern by analyzing their 2.5 Dimensional models. The result from MATLAB were useful to understand better the simulation results as well.

The outcomes of this technique could be summarized in patterns wind and air quality maps. Wind maps could be used to map the existing/potential/necessary ventilation paths and fields, essential in mitigating the heat island effect and pollution dispersion.

Air quality maps are the other outcomes that illustrate the urban wind comfort as an invisible but distinguishing parameter of livability.

Where the idea came from?

In the last decades, a compact city dilemma is questioning the relation between the densification and transformation of the existing urban tissue and its sustainability. By following the actual densification policies, made to obtain more sustainable cities, there would be the risk of affecting the urban environment through changing its microclimate. Cities heating up by the famous heat island effect and consequently increase in energy consumption during the summer time are only some of issues which makes us concern. Of course, these effects are more evident in cities with already compact tissue.

With the rapid development of urbanization, the economy and number of vehicles, the urban climate has worsened in recent years, causing serious urban problems. One of the most dramatic changes is the warming effect that cities have on local air temperatures. According to some studies, the heat-retaining properties of the building blocks of urban development can make cities up to 10 degrees Celsius warmer than the surrounding area. The average temperature in cities is going up more than twice as fast as the temperatures on the rest of the planet.

Thus, in this research it is tried to understand how the physical transformation of the cities could affect its microclimate and how this knowledge could be utilized to improve our cities environmental quality.

For whom and how?

Urban forms have always fascinated urban planners, urban designers and architects, as a tool to improve the sustainability and performance of urban areas. Wind maps could be useful to City and environment managers by helping them evaluatingthe effect of urban developments and new proposals on urban ventilation.
Wind maps could be used to map the existing/potential/necessary urban ventilation paths and areas, essential in mitigating the heat island effect and pollution dispersion. Air quality map is the other outcome of which an invisible but distinguishing parameter of livability; wind comfort and so on.

The state of the art

In the book called *the compact city, a sustainable urban form?* [1] It is addressed some of the questions raised about the conception of the compact city from social, economical and environmental point of view. According to this book, it is not clear if the compact city is the best or only way forward to obtain more sustainable cities. It is argued, "While there may be strategic benefits, the impacts of the compact cities are likely to be felt local". They tried to examine the complex relation between high density living and mixed up environment and a high quality of life. A great degree of uncertainty in theory and in particular issues surrounding the compact city debate exist. It is argued, "Complexity and uncertainty mean that a precautionary principle should be applied in relation to the development of more compact form." In this paper, it is tried to examine the morphological changes of urban form from an urban ventilation point of view. To see how different forms of morphological realization could have negative or positive effect on urban microclimate.

Urban heat island effect is one of the major problems faced in the process of urban microclimate changes. In a work called *a simple method for designation of urban ventilation corridors and its application to urban heat island analysis* [2] it is confirmed that ventilation is a key parameter in mitigating heat island formation. They tried to map the urban wind ventilation , using the concept of “building frontal area index”, in the study area of Kowloon peninsula of Hong Kong as an example of a dense, sub-tropical urban environment where ventilation is critical for human health. Using the map of frontal area index, the main ventilation pathways across the urban area are located using least cost path analysis in a raster GIS. Comparison of the pathways with a map of the urban heat island suggests that ventilation is a key parameter in mitigating heat island formation in the study area.

Heat island effect could highly effect the energy consumption trend in urban areas. The consumption patterns of cities are severely stressing the global ecosystem. The world’s total energy consumption in 2006 was equivalent to a constant-use rate of 16 terawatts (1 terawatt, or TW, equals 1 trillion watts) [3]. Of that, an average rate of 6.7 TW was consumed in 86 metropolitan areas in the Northern Hemisphere.

This fact shows the importance of knowing what happens to electricity usage as the outdoor temperature rises. in a research done by *Opowers* [4] it has been examined an anonymized energy usage data across 18,000 homes from 3 different cities in the western part of US, which has faced blistering temperatures during July 2012 (the hottest July on record by that time). Analysis shows that increased air-conditioning during the hottest days of summer 2012 caused residential electricity demand, where More than 60% of US households now have central air conditioning, to shoot through the roof. As the result the average electricity usage of homes on a 103°-high summer day was registered up to 40% higher than during a typical summer day.

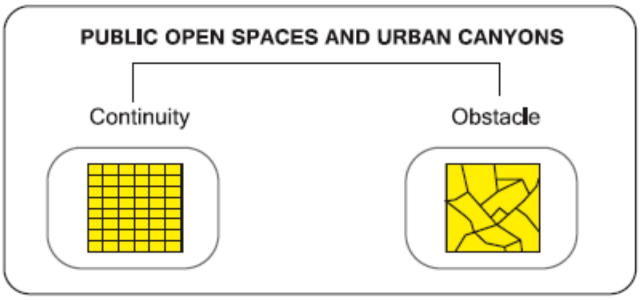
Methodology

Here it is introduced steps taken in the process of wind map-making, through a morphological approach.

1. Analyze of the compact cities tissues in order to find the prevailing patterns of the compact city. Framework: based on urban landscape model, patterns of different compact cities were selected from all around the world. A work based on the studies and recognition of urban forms extracted from the book called Cities and Forms: On Sustainable Urbanism. This method was employed in selection of the compact cities [5].

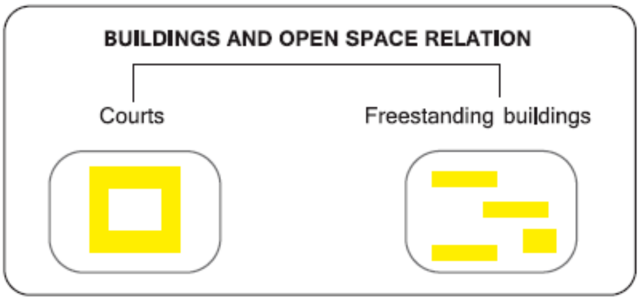
2. Compact cities prevailing patterns categorization, by identifying the possible wind flow areas. This concept takes in to consideration three main urban Items, in order to distinguish patterns from each other, 1- Buildings (built-up area), 2- Paths (streets and possible urban canyons) and 3- Open areas.

Paths:
According to the knowledge of fluid dynamics, streets network could be formed in a manner to ease up the air fluxes and even amplify them which I have called them *continuity network*, or they could form barriers against the wind flow, in this case they are called *obstacle network*.



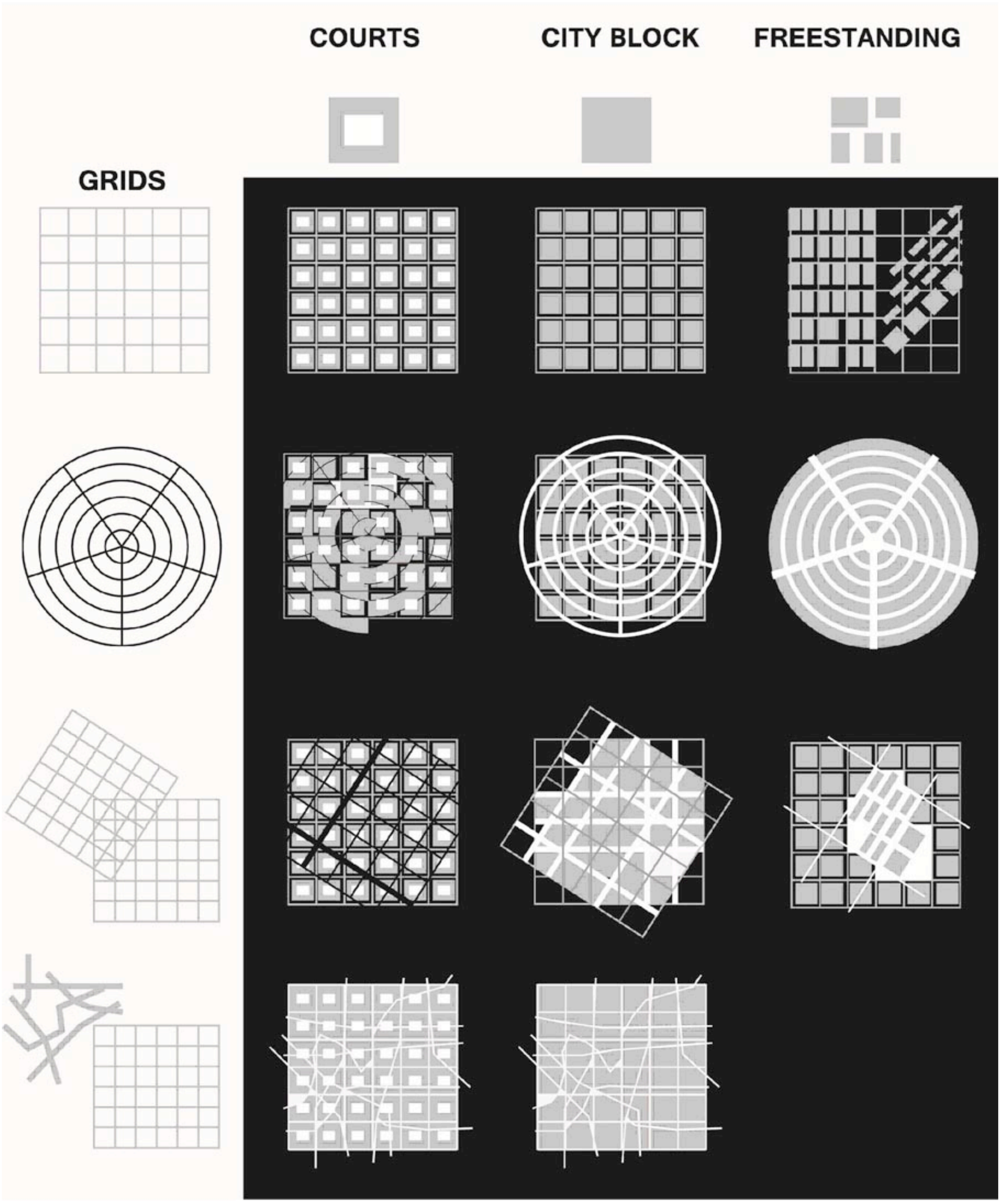
Scheme 1. Network public open spaces and urban canyons regarding to the wind flow
Source: Author

Open areas:
This type of urban space could be analyzed at two different scales; first, the Urban level such as parks and piazzas, and second the District level such as micro open spaces around and within buildings. Mapping the Parks and piazzas as they are simply distinguishable by the streets and built environment. What is of interest we can find at district level, where the relation between buildings and open spaces are translated in to; open spaces surrounding the buildings, here called *freestanding buildings* and buildings surrounding the open space, here called *Courts*.



Scheme 2. Relation between buildings and open spaces regarding to the wind flow
Source: Author

The assumption here is that the wind flows in the courtyards are that slow in relation with the other open areas and their effect on the overall urban ventilation is so minimal that in mapping the urban wind flow areas we can even disregard them. Here is to say this assumption has been approved after the wind simulation of different compact patterns in this research.



Scheme 3. Taxonomy of patterns, defined by
topology based on the patterns recognition concept
Source: Author

By adopting this methodology, patterns are divided in to preliminary groups with the possible same or close air fluxes according to the similarity of their morphologies as followed: ***orthogonal grid, irregular grids, hybrids, linear orders and city enclaves.***

Scheme 4. Selected samples
Source: Author

This framework was implemented for eleven pilot-studies, even though, in a specific city analysis regarding to the scale of the city, it is possible to arrive to other kind of morphological groups. A serious of samples with densities ranging between low, medium and high have been selected for each category.

After selecting the samples, the next step is to analyze and measure their morphological properties such as built and un-built area, density and roughness that in this research has been done by the mean of algorithms created in the MATLAB software [6].

In a parallel work, the wind flow of each sample is simulated by the ENVI-met software, using the computational fluid dynamics method, at hottest period of the year regarding to the local climate of the chosen sample. The main outcomes are the maps representing the microclimate condition such as flow speed, temperature and direction at different elevations from the ground.

Interpretation of outcomes

The outcome has been study in numerical and qualitative way for each sample and the results are crossed-comparison.
Numerical analysis includes:

- The change in airflow velocity and temperature between the inflow and the average wind flow on site at 3 different elevation (First cut: 3m – Second cut: 9m-15m – Third cut: on the model's top);
- The velocity and temperature variation between three cuts;
- Comparative vision between samples total floor area, built area footprint, built area intensity (volumetric and surface area), mean roughness;
- histogram relation between wind speed % at first cut regarding the prevailing wind and samples' density;
- Histogram relation between air temperature changes at first cut regarding the prevailing wind and samples' density.

What emerges is that in general increase in built-up intensity does not affect the urban ventilation and air quality in a direct and linear way. Nevertheless, individual analysis on each sample confirms that it highly depends on the amount and form of the possible wind flow areas (continuity and obstacle form of the un-built areas). The so-called network of un-built area could be in favor or against the wind flow, independently from the incoming wind direction. Consequently, it could increase/decrease the quality of temperature exchange process between buildings and flow around them. The better this network is formed in favor of wind flow, such as orthogonal or linear order patterns with specific morphological factors, slower would be the formation of heat island and faster would be the urban ventilation process.

In specific in order to have a better performance, a pattern should have factors as following:

- at the same density, the continuity street network performance is much better than obstacle street network
- high built area porosity: even with high-density patterns such as the New York City pattern, with skyscrapers, due to the high porosity of the pattern registers a good performance.
- good street canyons morphologies: width-height ratio> 1, length-height ratio> 1, length-width ratio>1
- good grains porosity: the court yard buildings have better temperature exchange than massive building blocks, whether it highly depends on the % of the court yard surface to the total building footprint or better to say it depends

on the court's form (width-length and width-height ratio). In cases where its form is closer to rectangular and the width-height ratio is < 2, the court performance is major.

- good street canyons and buildings mass relation: average building width/length to average canyon width is = < 2.

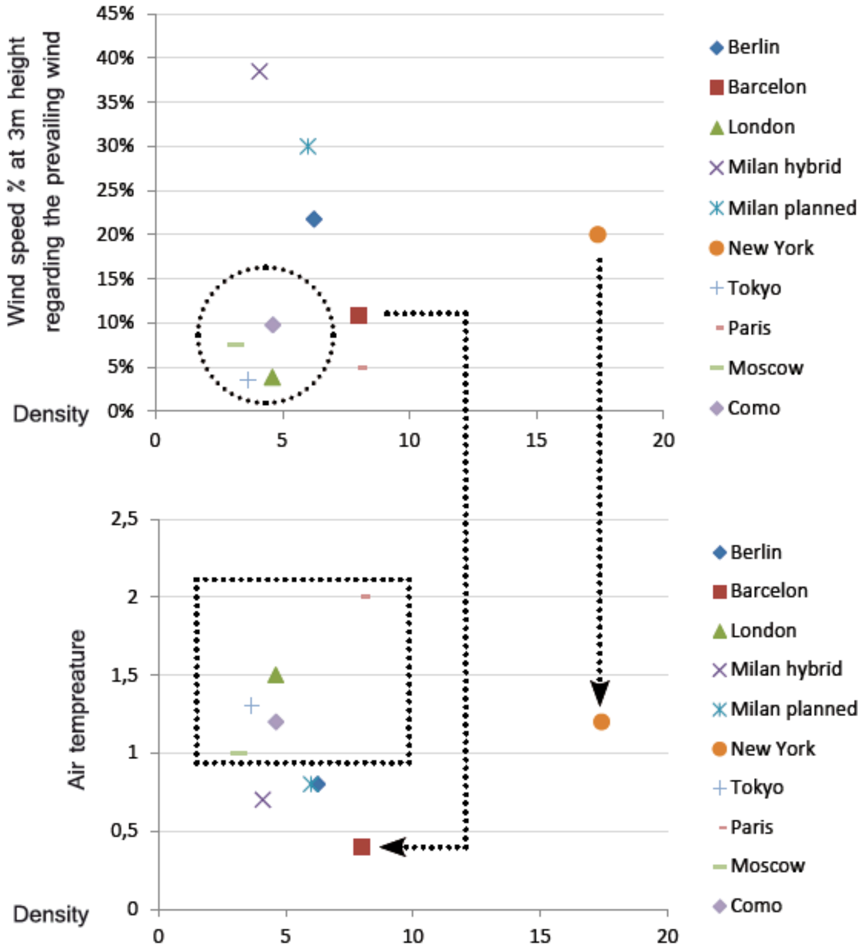


Chart 1. Comparative vision,

On the top) relation between samples density and wind speed (percentage of the wind velocity at first cut regarding the prevailing wind speed).

On the bottom) relation between samples density and wind temperature (difference from air temperature at first cut and prevailing wind temperature)

Concern and future work

What is suggested as future work is integration of the patterns wind profile with GIS data, in order to provide cities Wind Map. Results obtained from MATLAB an ENVI-met could be stored as database for GIS. In GIS, each category of pattern would be related to a specific layer through an automated recognition process of urban objects [7]. In this way, it is possible to map the wind velocity map, air temperature map and urban ventilation/ wind flow quality map. These maps could help recognizing the necessary interventions or evaluating the future urban projects.

These data are modifiable regarding to the seasonal and climate condition of the city under study. Potential users can use the proposed set of patterns to create wind maps, add new patterns to it in order to compare different design solutions, or add new groups based on their necessity. These possible modifications make it highly flexible to use in different case studies as well.

References and further reading

1. M. Jenks, E. Burton, K. Williams, Compact City Series: The Compact City: A Sustainable Urban Form? , 2005;
2. Man Sing Wong, Pui Hang To, Jingzhi Wang, Janet E. Nichol, A simple method for designation of urban ventilation corridors and its application to urban heat island analysis, Building and Environment, Volume 45, Issue 8, August 2010, Pages 1880–1889
3. Guang J. Zhang, M. Cai, A. Hu. Energy consumption and the unexplained winter warming over northern Asia and North America. Nature Climate Change, 2013; DOI
4. Opower's is a big-data and energy blog, "Outlier," which leverages energy usage data across 50 million US households. They works with 80 utility companies to empower millions of customers to understand their energy usage in U.S.http://blog.opower.com
5. S. Salat, F. Labbé, C. Nowacki, "Cities and Forms: On Sustainable Urbanism", CSTB Urban Morphology Laboratory, 2011, 2705681116, 9782705681111
6. E. Morello, C. Ratti, 2007, "Raster Cities: image processing techniques for environmental urban analysis", in K. Thwaites, S. Porta, O. Romice, M. Greaves (editors), Urban Sustainability through Environmental Design: approaches to time, people and place responsive urban spaces, Spon Press, London, UK, pp. 119-122
7. A. Peeter , Y.Etzion , "automated recognition of urban objects and their morphological attributes using GIS,"ISPRS Archives Vol. XXXVIII, Part 4-8-2-W9, 2010

PATTERN PROFILE

CITY	PARIS
area	632431
tot. floor area	3601530,88
built area m2	450191,36
built area %	0,71
built volume	1708,42
mean_height	24,00
max height	24,00
mean roughness	2,05
Prevailnig wind roughness	1,81
Prevailnig wind direction [summer wind]	247
wind Speed in 10 m ab. Ground [m/s]	4,1
temperature [celsius]	20
temperature [kelvin]	293

URBAN TEXTURE

Dimention: 1600x1600 m

SAMPLE AREA

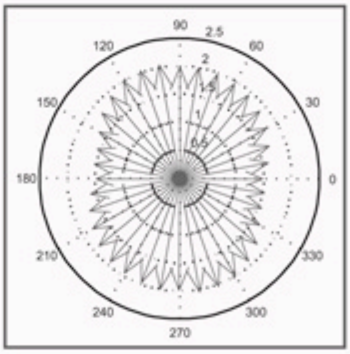
Building foot print

Border line

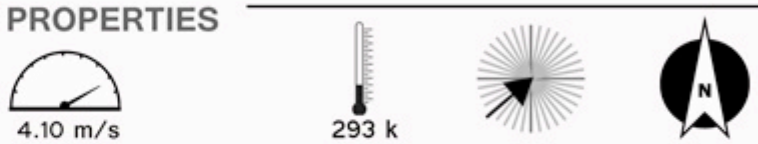
DENSITY

total floor area / built area [m2/m2]	8,00
total floor area / total parcel area [m2/m2]	5,69
covered area / total parcel area [m2/m2]	0,71
built volume / total parcel area [m3/m2]	17,08

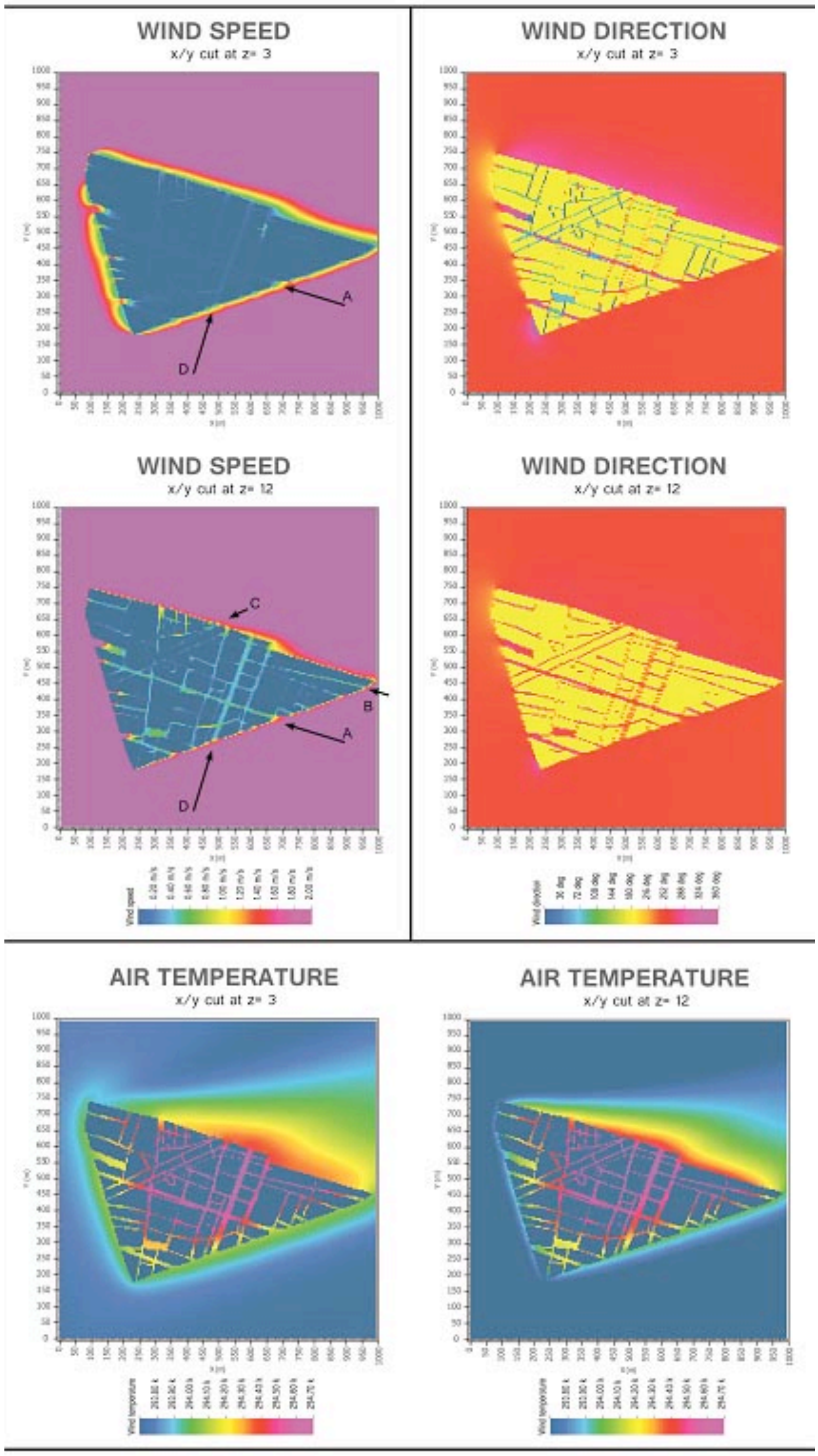
ROUGHNESS VECTOR



WIND PROPERTIES



Scheme 5. Example of Irregular grid pattern profile, Paris - France



Scheme 6. Example of Irregular grid, microclimate pattern profile, Paris - France