# Contribution to the study of the effects of urban morphology on flow patterns at block scale

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## Context and motivation

Environmental issues become increasingly critical, and especially the energy consumption and GHG emissions of buildings, districts and cities. These aspects are closely related to the microscale thermal and aerodynamic conditions, which also affect the urban heat island intensity and citizens health and comfort. In the same time, usual architectural practices evolve. The integrated design of bio-climatic urban blocks and eco-neighborhoods is increasingly promoted rather than the design of energy efficient isolated buildings only.

Building groups should yet be considered as a whole, in their interaction with their environment and between their constitutive elements. New design challenges arise for architects, urban planners and engineers as they have to work on urban units that include buildings and their adjacent outdoor spaces. Those not only have to be designed to be comfortable: they are critical parts of an interacting system and directly impact the building aerodynamic and thermal solicitations. A better understanding of the urban microclimatic processes and the improvement of usual design tools become therefore essential to support an integrated urban and architectural design.

Urban physics is a scientific and multi thematic discipline touching on engineering subjects linked to physical phenomena that occur within cities (for more details see [1]). Urban air flows are a common factor in most of the related topics and present a challenging concern: in addition to city's complexity as an object in itself, recirculation and turbulence phenomena that develop in urban areas and greatly impact wind fields remain an issue. Those interfere with several heat and mass transfers on several spatial scales and influence urban microclimates, ventilation and the building energy balance.

The current work aims at understanding how urban morphology affects the aerodynamic phenomena that occur within cities and to outline connections between urban forms and

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physical exchanges. To provide for a relevant analysis of the related processes and a broader applicability of the expected findings for a wide diversity of urban patterns, we designed a trans-disciplinary methodology. It combines an urban and architectural analysis of real urban configurations which are reviewed in [2] with a physical approach that uses detailed Computational Fluid Dynamics (CFD) models.

## Methodology

The methodology is composed of five main steps:

- First, the relevant spatial scales and the corresponding physical processes that interact to produce the local thermal and aerodynamic conditions within the urban canopy layer are outlined.
- Then, urban morpho-metric parameters that link urban form features to physical exchanges are reviewed, and studies carried out for generic urban configurations are analyzed. Main morphological factors affecting urban air flows and heat transfers are thus identified.
- Combining these results with a morphological analysis of real urban forms, two generic typologies mainly based on topological criteria and suitable for urban aerodynamics studies are designed:
  - isolated buildings: the cube, parallelepiped, L, U and patio,
  - urban blocks: the cube array, row block, U block, enclosed block and the continuous block with multiple courtyards.
- In parallel, the CFD model is validated by comparison with detailed data sets from wind tunnel tests [3] and LBM-LES [1] [4] for an isolated and a multi-obstacles case. This highlights methodological issues especially in terms of boundary conditions and turbulence modeling, and supports the choice of the actual modeling strategy and settings.
- Finally, each type is modeled using Ansys Fluent 15.0. Outputs are analyzed and compared in terms of mean wind fields and recirculation phenomena. Flow patterns that occur next to obstacles and physical processes that lead to the observed flow fields are more particularly examined as they have direct effects on the energy demand, natural ventilation and pedestrian comfort.

## Results

Distinct flow features can be identified around buildings. Those differ depending upon the incident flow properties and void formal features which correspond to particular building shapes and layouts.

[1] Lattice Boltzmann Method - Large Eddy Simulations

Flow patterns around simple isolated sharp-edged obstacles immersed in a turbulent boundary layer are already fairly complex. Three main recirculation phenomena develop: the first upstream, one on each side and on top of the obstacle and a bigger one downstream. They are characterized by the formation of vortices and a relative increase or decrease in air velocity. Courtyards can significantly increase the complexity of these flow patterns, as additional trapped vortices or other recirculation phenomena develop. Some preliminary results for the cube and the patio types (single building typology) are shown in figure 1.

In cases of building groups, especially when they are composed of disconnected solid masses or empty spaces, air flows significantly increase in complexity (not shown here). The flow field results of intricate interactions between several recirculation, wakes and turbulence phenomena that are produced by each obstacle, which are themselves generally exposed to disturbed flows. Flow features are therefore very case specific and local. The comparison between different urban block configurations in terms of building relative contiguity, compactness and layout shows that the void formal features lead to very distinct flow patterns. This greatly affects ventilation processes within the building group and interferes with the immediate environment. On a bigger scale, urban blocks can also significantly affect the boundary layer structure, especially when considering three dimensional heterogeneous forms.

## Conclusions

A better knowledge of the aerodynamic mechanisms that occur within urban fragments is essential in order to better understand urban microclimates and heat island phenomena, as well as to improve citizens health and comfort and building energy efficiency and conservation. Accounting for realistic convective heat fluxes for an urban block and its surroundings, a roughly 10% increasing or decreasing of a building energy consumption respectively in summer and winter was assessed in [5].

However, cities and urban aerodynamic processes are very complex. In order to better understand those physical processes and to link them with urban morphological features, we have designed an original methodology based on a geometrical abstraction of worldwide existing urban patterns and detailed CFD simulations. This exploratory and trans-disciplinary work aims at providing findings suitable for fundamental and more applicative purposes.

Building and urban block scales are addressed since the study aims to investigate aerodynamic mechanisms next to buildings. Single generic building and urban block types are designed and the corresponding air flow patterns are examined using CFD simulations. When a single - or a group of - obstacles interact with the boundary layer, complex recirculation phenomena occur within the canopy. They depend in particular on the inflow direction with regard to the open space directionality and on their topological features and relative dimensions.

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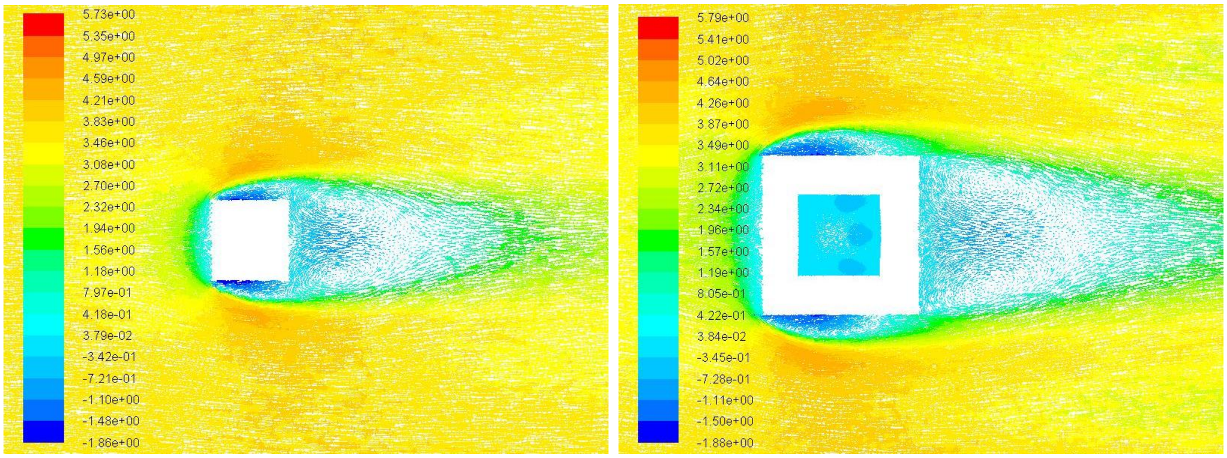


Figure 1: Preliminary results: Mean velocity field colored by X velocity for the cube and the patio at 5m high. Obstacle height:10m.

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