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Wind pressure distribution influence on natural ventilation for different incidences and environment densities

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Abstract

Natural ventilation is of increasing interest in building industry because of recent focus on environmental concern, considered with both comfort and economical criteria. The aim of this study is to investigate how wind may induce natural ventilation, with focus on wind incidence and large scale environment density influences. These parameters modify flows inside and outside buildings. Numerical dynamic simulations are achieved for a standard office building using pressure coefficients obtained from a parametrical model. Simulations allow to describe inside building air flow for three incidences: 0°, 45°, 90° and three theoretical environments: open, suburban and urban. Originality of this study is to work with both vertical and horizontal pressure coefficient gradients. Results show how important horizontal gradients are in air flow comprehension. Urban wind driven ventilation potential is also discussed. Some words are said on existing tools limitations. The need for further studies is illustrated in order to obtain handy pressure coefficients prediction tools and to optimize openings mechanical regulation. The all study falls under the step of sustainable architecture.

Keywords: Natural ventilation; Indoor air flow; Pressure coefficient; Wind; Office building

1. Introduction

1.1. Natural ventilation in building and energy

One of the fundamental aspects of architecture is to provide comfort to the inhabitant. This is done by wall insulating, heating, protecting from the sun and managing fresh air intake. In this context, natural ventilation is an important tool when used along with sufficient thermal inertia. It enhances air quality by dissolution of pollutants and thermal comfort by refreshing building's mass, especially when night cooling is created.

But interest in ventilation is double since energy concern takes more and more place. This concern has emerged last decades, brought by energy efficiency objectives and cost saving opportunities. On one hand, ventilation may be a powerful cheap temperature control tool in buildings if well conceived. On the other hand, it can be an important potential of energy losses if not. In winter time, fresh air intake represents around 30% of office buildings heating energy needs. And in summer time, extensive night cooling in buildings with strong inertia can be developed to avoid day overheating and expensive and energy consuming refrigerating systems. These examples illustrate the place of mechanical or natural ventilation in energy concern.

Ventilation based on natural forces (buoyancy forces or wind pressure) should always be preferred to mechanical ventilation. In European climates, natural forces can efficiently complete comfort and energy objectives without fans' energy consumption. But, therefore, it must be well conceived and regulated. Mechanical ventilation should be limited to particular situations when sufficient natural air flow cannot be achieved.

1.2. Wind and natural ventilation

Wind influence on natural ventilation is obvious. By creating high and low pressures on buildings' different faces, wind creates air flows inside buildings. These

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movements are strongly dependents on wind pressure gradients. Wind flow and wind pressure distributions on buildings are then important fields of investigation explored by lots of authors.

Some of them try to determine pressure profiles on buildings for different incidences [1], neighbour buildings configurations [2] or local environment densities [3]. Others try to describe buildings or topography influence on wind flow [4,5]. Finally, some authors investigate particular configurations as street canyon [6]. But all these studies are made aside where a systematic approach appears necessary to obtain effective comprehension of pressure distributions on buildings [7].

Only a few authors study connection between environmental interferences created in wind flow and natural ventilation potential, partly because softwares combining thermal study and air movements are quite recent, partly because it is a younger concern and partly because it is dependent of more accurate knowledge in fluid dynamics. In particular, description of air flow downstream obstacles needs further developments. Some studies although exist, made with wind tunnel experiments [8] or numerical tools. Among these last the study of Gratia et al. [9] is of greatest interest because it discusses natural ventilation in office buildings for different environments and wind influences. Major limitation of this study is to use only vertical pressure distributions. Results are then theoretically correct for a building of infinite length.

1.3. Aim of this study

This study follows Gratia et al.'s. It goes one step forward by taking into account as well horizontal as vertical pressure coefficients gradients. Objective of this study is to bound complete description of pressure coefficients repartitions on building for different wind incidences and built environments with architectural concern about natural ventilation. Indeed architecture may be defined as the creation of a building in a particular context. High quality architecture for example is able to combine constraints of local and global context with particular programmatic, structural and aesthetic specificities. It is then necessary to pursue studies on environment influence on buildings to promote buildings of quality. Such study is then part of a sustainable architecture definition.

Practically, use of horizontal and vertical pressure distributions allows our results to be applied to real buildings. These results are then useful complements for architects and HVAC designers in buildings and systems design.

By numerical simulations this study will investigate inside flow and flow rates modifications for 0°, 45° or 90° wind incidence and open, suburban or urban environment. Urban natural ventilation potential will be discussed, as well as city densities limits. Importance of accurate knowledge of vertical and horizontal pressure gradients will be illustrated.

2. Theory

Before describing our study methods and obtained results, some theoretical notions can be useful.

Wind in lowest parts of atmosphere undergoes friction and viscosity effects. Wind behaviour can be described by the boundary layer model. Such a layer develops itself between the ground surface and firsts hundreds meters altitude. Wind profile in this boundary layer can be accurately enough described by an exponent profile:

$$V_z = V_g\left(\frac{z}{h}\right)^{1/\alpha} \tag{1}$$

where V_z is wind speed at height z; V_g, wind speed outside the boundary layer; h, the layer height; and α, a coefficient describing ground density. Index g is chosen to represent the free stream wind. This wind can be represented by the "gradient wind" model [10].

Greater ground density will increase boundary layer height and decrease α value. Following values are proposed by Melaragno [11]: boundary layer height can be set to 275 m in open environment, 365 m in suburban environment and 460 m in urban environment while adequate values for α are, respectively, 7, 4.5 and 3 in the same environments. Exponent $1/\alpha$ then takes, respectively, the 0.14, 0.22 and 0.33 values.

Using such determined values is of course simplified. But more accurate developments of the relation between ground configuration and wind profile description are useless here. Indeed this study worked with three theoretical ground configurations and did not investigate continuous density variations.

Simple algebraic developments allow to determine suburban or urban speed from meteorological data usually given for open environments. Following development is based upon hypothesis of constant gradient wind speed above boundary layer. Considering 1 and 2 indexes as two different environments, this hypothesis is written:

$$v_{g_1} = v_{g_2} \tag{2}$$

$$\frac{v_{z_1}}{(z_1/h_1)^{1/\alpha_1}} = \frac{v_{z_2}}{(z_2/h_2)^{1/\alpha_2}} \tag{3}$$

$$v_{z_2} = v_{z_1}\left(\frac{h_1}{z_1}\right)^{1/\alpha_1}\left(\frac{z_2}{h_2}\right)^{1/\alpha_2} \tag{4}$$

Using h and α values given above, passing from one environment and altitude to others is easy.

Next notion exposed here is the pressure coefficient Cp:

$$\mathrm{Cp} = \frac{p - p_{\mathrm{ref}}}{p_{\mathrm{ref}}} \tag{5}$$

$$p_{\mathrm{ref}} = \frac{1}{2}\rho v_{\mathrm{ref}}^2 \tag{6}$$

Where p is the measured pressure on buildings sides and p_{ref} is a chosen dynamic reference pressure. Such definition allows to compare results of various studies as long as the same reference is chosen. Usually reference speed is