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Computational analysis of wind interactions for comparing different buildings sites in terms of natural ventilation

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ABSTRACT

Nowadays building designers have to face up to new strategies to achieve the best sustainable building designs. Well planned natural ventilation strategies in building design may contribute to a significant reduction on building's energy consumption. Natural ventilation strategies are conditioned to the particular location of each building. To improve natural ventilation performance of a building, the analysis of the influence of the location and the surrounding buildings on wind flow paths around the design building is a must. New computational tools such as Computational Fluid Dynamics (CFD) are particularly suited for modelling outdoor wind conditions and the influence on indoor air conditions prior to building construction. Hence, reliable methodologies are necessary to support building design decisions related to naturally ventilated buildings prior to construction.

This paper presents a case study for the selection of the best future building location attending to natural ventilation behaviour inside the building, conditioned by different evolving environment. A validated CFD model is used to represent outdoor and indoor spaces. The methodology explains how to qualitatively and quantitatively analyze wind paths around and through a building to quantify the natural ventilation performance. The best location, from two real possible solutions, is then selected.

1. Introduction

For the last 10 years energy efficiency has become more popular, mainly because of the climate change and environmental degradation. There is an increasing necessity to reduce the amount of energy required to provide thermal comfort conditions in buildings. More sustainable buildings are then designed thanks to the development and advances of new design techniques [1].

Ventilation is a must to ensure a high indoor air quality and comfort. Methods for ventilating a building may be divided into mechanical/forced and natural strategies. Mechanical ventilation requires an external input power supplier to work while natural ventilation (NV) relies on wind and thermal buoyancy as driving forces [2]. The potential benefits of NV include lower energy costs compared with mechanical ventilation, as well as an improved indoor environmental quality and occupant satisfaction [3]. Therefore to achieve more sustainable buildings, designers are promoting the utilization of NV to improve and decrease the building energy consumption. While NV benefits may be achievable, its implementation and design presents certain challenges since it requires careful analysis of many variables.

Natural ventilation, also called passive ventilation, uses natural outside air movement and pressure differences to both passively cool and ventilate building as early stated. The NV approach design requires an appropriate understanding of principles of local wind patterns, climate conditions, airflow around the building, building orientation, pressurization and façade design [4]. Design of naturally ventilated buildings is also influenced by the airflow through the building. Driving pressures derived from wind and thermal buoyancy are low compared to those produced by fans in mechanical ventilation systems. Therefore the buildings shaping, orientation relative to prevailing wind direction(s) and façade design should be considered in the initial design stages of construction to exploit local wind natural forces to drive the air through its interior.

Natural ventilated buildings do not only suggest that natural airflow influences building design, but also that it might be a concept-making factor of the entire project. Building designers should take into account all these variables, even when its quantification before building construction would be not an easy issue. In fact, increasingly new technology methods allow nowadays designers to evaluate different architectural solutions to improve

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natural ventilation in its design stage. What happens then is that building designers often do not consider NV solutions due to its lack of expertise on using proper technologies to evaluate and implement it. Thus, designer's awareness and understanding of the location potential is mandatory for proper design of a naturally ventilated building which reaches its maximum energy advantages. The relative position of the building with respect to surrounding buildings and prevailing winds may affect the whole performance of the building. Therefore when designers have the option for choosing the building's position and orientation, the most energy efficient solution should be selected. Often, it is not possible to choose the building position or there is no space to rotate the building. Even in these cases, designers should choose the best façade opening distribution to optimize the natural ventilation resources of the location or modify the interior layout. Anyway, evaluation should be done for each particular case that might contribute to make buildings more site specific.

The evaluation of NV performance pretends to provide information concerning indoor/outdoor airflow parameters in a building. There are many recent applications for predicting the ventilation performance of buildings. Ventilation can be typically predicted or evaluated using a wide range of methods: analytical models, empirical models, small and full-scale experimental models, multi-zone models, zonal models and CFD models. An overview of the methods is summarized by Chen [5], Yuguo and Heiselberg [6]. Among all of them, Computational Fluid Dynamics (CFD) simulations have been the most popular in recent years [7–10]. CFD has been widely used for simulation of wind and air movement in existing buildings. Literature is profuse in documents based on CFD direct application and experimental validation in order to design wind behaviour of NV in buildings [11–19]. Nevertheless, CFD has not been almost used in building early design stage, in which CFD can help building designer to achieve better and more detailed understanding of issues involving ventilation. Additionally, in this stage, there is no access to full-scale testing facilities although several studies have been done in CFD and reduced-scale models [21]. CFD enables building designers to choose the best constructive solutions by simulation techniques and not by trial-and-error experimental techniques, which need much time and economic resources to be performed. Nevertheless, CFD simulations have to be validated to assure that results are reliable.

To simulate correctly the specific conditions of each location, a complex analysis of the building and of the background is necessary. Developing reliable CFD models requires a high level of expertise, which in many cases may not be available [22]. A wide CFD knowledge is essential to well define an indoor computational model and handle complex boundary conditions [23,24]. This is a handicap to be solved in the future. Nevertheless, in recent years, several standards and guidelines have been created to help designers to produce credible and verifiable CFD results [25–27]. In addition, CFD developers are increasingly creating more user-friendly software to allow non-specialized companies to work with CFD. In fact, companies are paying increasing attention to create more and more specialized CFD simulation divisions. Even when high computer power is necessary, parallel simulations help to reduce computational times. Although this methodology involves certain computational capabilities, every day designers are more prepared to integrate engineering analysis with architectural design.

Natural ventilation offers the opportunity of reducing mechanical requirements of Heating, Ventilating and Air Conditioning (HVAC) systems by using the natural driving forces of external wind and the buoyancy effect from internal heat dissipation. Wind patterns around buildings affects ventilation, infiltration rates and associated heat losses through it i.e. energy consumption of the building. With regards to the location of the building, the analysis of surrounding wind effect on the prevailing wind direction will be crucial when designing the building in such way that wind pressures, that will drive air flow through its apertures, will be created to passively ventilate the building. Wind analysis should be locally done, since wind pressure varies considerably due to its interaction with urban context, like buildings, and natural environment. These interactions create complex air flows and turbulence [20].

The present study shows a coupled CFD analysis of the effects of different building locations on the indoor airflow distribution of a naturally ventilated building in an urban environment. Selection of the future location to improve wind usage for NV purposes is carried out from the building design stage. Air velocity, indoor air change rates and air velocity streamlines are analyzed to better understand natural ventilation effect in the building. Impact of surrounding environment, including the main buildings, on the air flow behaviour through the building are modelled by CFD. Other aspects, like temperatures and sun heating, are assumed to be constant, while some others are already defined: building shape, façade openings and indoor layout.

The objectives of the study are outlined in Section 2. The geometry of the building and surroundings are described in Section 3. Section 4 describes the computational model and the followed validation procedure. Section 6 presents the simulation results and its discussion. The paper conclusions are summarized in Section 7. Finally, last sections are “Acknowledgements” and “References”, with the acknowledgements and consulted bibliogrphy, respectively.

2. Objectives

Designers have to face up the ability of dealing with complex designs that take into account many requirements to improve building energy performance i.e. local environmental conditions and building surroundings. Designers should choose, when possible, between more or less energetically location alternatives using an objective criterion. One of the most architectural implications on an advanced naturally ventilated building is the consideration of the influence of surrounding environment regarding wind patterns [28].

The present paper follows a design methodology to face up the site selection procedure of a building. Relationship between building location, surrounding environment and natural ventilation is examined. Two available sites for the building are analyzed and compared under a NV point of view. The objective is to demonstrate that comparative results of different architectural alternatives should be done to get objective criteria to select building location at the design stage. The methodology summarizes a qualitatively and quantitatively analysis to choose the best building site using a computational fluid dynamics technique through a case study. The computational model is created with a systematic procedure and validated with full-scale measurements to assure credible results.

The primary goal of this study is to offer a better understanding of the building location presuppositions associated with the utilization of natural wind driving forces to improve natural ventilation and therefore building energy efficiency.

3. Description of building and surroundings

The present case study analyzes the design and construction of a modular sustainable and energy-efficient building. The aim of the entire project is to promote awareness of designers, students and society towards energy efficiency design of buildings and promote specialization of the professionals involved in this field. The