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Numerical simulation and wind tunnel experiments on wind-induced natural ventilation in isolated building with patio

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This paper deals with studying of the aerodynamics characteristics in a residential building with a patio system connecting the inside with the outside. The numerical simulation is based on the resolution of the Navier–Stokes equations in conjunction with the standard k-ε turbulence model. These equations are solved by a finite-volume discretization method. The comparison between our numerical and experimental results developed using a wind tunnel shows a good agreement and confirms the validity of the numerical method. This proposed design presents an outlining environment suitable building in Tunisia.

1. Introduction

The positions of window openings are important parameters determining the effectiveness of wind-driven cross-ventilation in buildings. Hence, natural ventilation can save the energy consumed by the heating, ventilating, and air-conditioning systems in a building if it provides acceptable indoor air quality and thermal comfort levels. In this context Bu et al. [1] studied the accurate prediction of effective air change rate; nevertheless so far little is known about this kind of ventilation issue. Wu et al. [2] presented an approach using the CFD (computational fluid dynamics) based simulations to compare the numerical predictions with the original architectural insight for a verification of the architect's thinking in his realization of the design purpose. Tablada et al. [3] studied the morphological characteristics of the Historical Centre. From this study, appropriate locations have been selected for field measurements and a limited comfort survey, from which a tentative summer comfort zone for residential buildings in Old Havana was suggested. Based on the historical overview, the measurements and the survey, some preliminary design recommendations for residential buildings in Old Havana were provided. Ntinas et al. [4] conducted an experiment inside a wind tunnel and the air velocity and turbulent kinetic energy profiles were measured around two small-scale obstacles with an arched-type and a pitched-type roof. Derya Oktay [5] evaluated the housing settlements in Northern Cyprus where the vernacular urban and architectural patterns provide useful hints for designing more sustainable environments. The courtyard, the element providing the most significant climatic utility in a hot climatic region, will be introduced as a design tool for the new developments. Schulze et al. [6] studied state ventilation air flow rates were systematically simulated using both analytical and airflow network methods for different boundary conditions such as temperature and pressure differences across openings for different opening types. Iruleg et al. [7] studied the building design strategies based on the full integration of active–passive solar technologies and passive design criteria in order to achieve an energy self-sufficient proposal, providing high quality of life to its occupants. Faggianelli et al. [8] developed the natural ventilation potential assessed by a radar plot which groups the main climate indicators for comfort ventilation and passive cooling. Tracer gas measurements on a seaside building in Corsica show that high air change rates are reached by cross ventilation during day. Al-Sallal et al. [9] developed a sustainable house designed following an integrated process of design and performance evaluation. The design achieved considerable improvement over a typical Emirati house case: 59% reduction in the greenhouse gas emissions and utility bill. Kacher [10] represented building elements to quantify energy consumption. Conceptual modeling is a way to represent a domain order to explain some actions. Terrados et al. [11] described and analyzed the Patio.

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The advantages of using strong architectural ideas accomplished a harmonious dialogue among the domestic energy mechanisms. Du et al. [12] clarified the definition of building microclimate in free-running buildings and the relationship with summer thermal comfort. Field measurements were conducted to investigate the microclimate in a Chinese traditional vernacular house. Subsequently, the results of measurements were compared with a dynamic thermal and a CFD simulation in order to determine the building microclimate and thermal comfort of the present vernacular house over the period of an entire summer. The field measurements show the present Chinese vernacular house having its own independent building microclimate in summer, which is in accordance with the main character of microclimate in terms of different distributions of solar gain, air temperature and wind velocity in different spaces. Moradchelleh [13] developed the results of the research form a basis for general scientific, methodological, architectural, and planning principles of designing residential and public buildings. Moreover, some recommendations on developing of Iranian modern architecture of civil buildings with regard to national, Islamic, and cultural traditions are provided. Tonellia et al. [14] studied the real estate market of buildings and building components performance control. The best way to achieve them is through industrial products and prefabrication. Bang et al. [15] developed an integrated planning environment suitable for determining wind loads and snow deposition in planning construction in the cold climate areas. Such problems are now mostly solved by using wind tunnel experiments, rough assumptions or by experience. Calculations in two and three dimensions are performed on commercial fluid dynamic software based on Navier–Stokes equations. This paper deals with wind loads on buildings, ventilation of the attic of a small house, and flow patterns around groups of buildings. De Melo et al. [16] validated using wind tunnel data on odor dispersion around a complex pig farm facility comprising of two attached building. Luo et al. [17] studied models of cuboids obstacles to characterize the three-dimensional responses of airflow behind obstacles with different shape ratios to variations in the incident flow in a wind-tunnel simulation. Wind velocity was measured using particle image velocimetry to study the design impact of this building on the aerodynamic characteristics. Hedegaard and Balyk [18] presented a model that facilitates analyzing individual heat pumps and complementing heat storages in integration with the energy system, while optimizing both investments and operation. Chan [19] investigated an appropriate floor level of a residential building above which balconies should be incorporated. A 21-story residential building was modeled using "EnergyPlus". Simulation results indicated that, for a west facing flat, only the flats located on 15/F to 20/F can give acceptable environmental payback periods, ranging from 58.3 years to 40.7 years, i.e. within the lifespan (60 years) of a building. Mirko et al. [20] proposed a moving-horizon short-term optimization to determine near-optimal operation modes. They showed that this approach, applied to flexible energy systems without seasonal storage, have satisfactory efficiency and accuracy compared with solving problem for an entire year. Also, they confirmed it as a valuable pre-solve technique. Premrov et al. [21] demonstrated a possible avoidance of the latter energy related problem. The results point out that the total annual energy demand for heating and cooling depends on the increasing shape factor to a considerably higher extent in cold climate conditions with a lower solar potential (Helsinki). On the other hand, the analysis of the regions with a higher average annual temperature (Ljubljana) and solar potential in the heating period shows that the influence of highly attractive building shapes on the energy demand is evidently less important, especially when using the appropriate size and position of the insulating glazing.

According to these anterior results, paucity on the aerodynamic study of new building design has been noted. For thus, we have adopted in this paper a new design of an isolated building with patio. Numerical and experimental investigation has been developed. Such simulations are carried out to study the natural ventilation phenomenon.

2. Geometric parameters

Fig. 1 presents a 3D view of the building prototype with a height H = 0.09 m and a width W = 0.268 m. This prototype considers a residential building with a living room, a kitchen, a dining room, a bedroom, a bathroom and a patio system (Fig. 2). The patio system presents an important role in the natural ventilation of the residential building. In fact, the two different openings, localized in the first living room and the patio, permits the local microclimate moderation inside the building and refresh the contaminated air.

3. Numerical model

3.1. Mathematical formulation

The mathematical description of the present model is based on the Navier–Stokes equations [22–24], which in a conservative formulation are given as:

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho\, u_i)}{\partial x_i} = 0 \tag{1}$$

$$\frac{\partial(\rho\, u_i)}{\partial t} + \frac{\partial(\rho\, u_i u_j)}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_j}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial u_i}{\partial x_i}\right)\right] + \frac{\partial\left(-\rho\,\overline{u_i^{'}u_j^{'}}\right)}{\partial x_j} + F_i \tag{2}$$

$(i, j = 1, 2, 3)$where ρ is the density (kg m^{-3}), t is the time (s), x_i and x_j are the Cartesian coordinate, u_i and u_j are the velocity components on the i and j direction respectively (m s^{-1}), p is the pressure (Pa), μ is the viscosity (Pa s), δ_{ij} is the Kronecker delta function and F_i is the force component on the i direction (N).

In our case, the k-ε model has been used. The transport equations of the turbulent kinetic energy *k and it's dissipation* rate ε are written as follows:

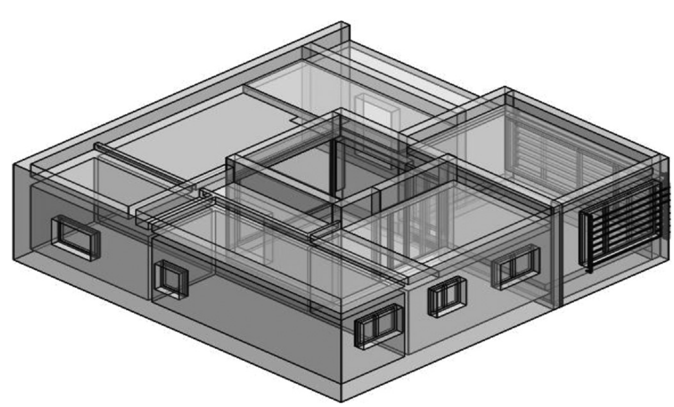

Fig. 1. 3D view of the building.