Outdoor ventilation and urban planning: comparative study between climatic measurements and CFD simulation

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ABSTRACT: Natural ventilation is essential to air quality and is one of the main strategies to achieve thermal comfort in urban areas in humid tropical regions, such as the study area in Vitória (Espírito Santo, Brazil). However, the wind is one of the most modified variables with the urbanization process, which makes it essential to understand the impact of urban settings in the ventilation natural flow. This phenomenon can be analyzed through simulations or controlled measurements. The measurements provide valuable aid in the understanding of the situation, but do not allow the prediction of other scenarios. However, in urban planning, it is important to consider the long-term phenomenon, so the computer simulation is an important tool for the prediction of future scenarios. Thus, the aim of this research was to conduct a comparative study between two method of study flow field in urban areas: field microclimate measurements and computational fluid dynamics (CFD). To this end, we selected a region in Vitória where the data were comparative analyzed. The similarity between the two methodologies predicting the measured value and especially the flow field behavior validate the CFD as a model capable of obtaining representative data of the existing situation. The results also point the software as a valuable tool for urban planning, able to predict different scenarios.

Keywords *Natural ventilation; Urban planning; Climatic measurements; CFD simulation*

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1. INTRODUCTION

The changes in urban settings interfere in climatic variables changing their magnitudes, forming a mosaic of microclimates, which makes the urban climate. The urban microclimate is receiving more attention in urban planning, because it directly affects people. It is related to a wide range of issues, such as external activities (Ahmed, 2003; Zacharias et al., 2001), comfort (NIKOLOPOULOU & Lykoudis 2006), air pollution (Yuan et al, 2014;. Taha 2015), energy (Dorer et al., 2013) and health (Harlan et al., 2006).

Natural ventilation is essential to the air quality and is one of the main passive strategies to achieve thermal comfort in urban areas in humid tropical regions, such as the study area in Vitória (Espírito Santo, Brazil). However, the wind is one of the most changed climate variables with the urbanization process. The effectiveness of urban ventilation depends on the wind interaction at different scales and cities natural and artificial features, whose urban planning should act to create conditions to ventilation promotion.

Different urban settings influence of various forms in ventilation natural flow, making it essential to understand how this occurs, whose analysis can be done by simulation or controlled measurements aiming to measure the impact of a given set of urban settings in wind speed. Measurements provides valuable aid in phenomenon understanding, but is limited to the existing situation. In urban planning, it is important to consider the long-term phenomenon, so computer simulation is an important tool for predict future scenarios.

Computer simulation can be made to a wide range of scenarios, which can represent the current situation, future prognosis and study of various urban settings proposals. Models of computational fluid dynamics (CFD), simulates actual physical processes that defines in set the wind behavior (Broekhuizen, 2016). CFD provides a complete picture of the behavior of the wind throughout the model and is well established in a variety of fields (Blocken, 2015).

Thus, the aim of this project was to conduct a comparative study between two methodologies of investigation of flow field in urban areas: the microclimate on-site measurements and the dynamic fluid software. For this, we selected an urban area in Victoria to conduct the measurements and posterior CFD simulation.

2. VENTILATION AND URBAN PLANNING

Urban ventilation studies are important for urban planners, architects, engineers and various professionals whose study object are the cities. For urban design, a comfortable external environment is crucial to provide activities and directly affects the social and collective dimension of the city (Gehl, 2010, Carmona, 2010).

It is noteworthy; however, that ventilation influence analysis in the urban environment can be performed at different times according to the study purpose. Given that the wind speed profile decreases as it approaches the ground and is influenced by the roughness (buildings and other obstacles) (Cocceal & Belcher, 2006), the passer-level is especially important for urban planning (Gehl, 2010) and is focus of several studies (Shi et al., 2015 Ayo et al., 2015). The flows in pedestrian level are set by the complex interaction between the wind and the built environment.

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Shi et al. (2015) identify at least three aspects of cities that affect wind on pedestrian level, mechanical comfort, thermal comfort of the passer, and urban ventilation. For this study we analyzed the urban ventilation, specifically wind behavior in relation to a selected urban setting.

In urban climate studies, one of the aspects that have been approached more often is the relationship of urban form with the microclimates formation. The setback areas, layout, height, width and depth of the built mass, associated with morphological features characteristics, such as topography, represent spatial urban configuration. The buildings arrangement, their shape and the presence of external obstacles play an important role in wind profile modification.

3. URBAN VENTILATION ANALYSIS METHODS

The wind directly affects the population, such as air quality and environmental comfort, among other things, so it is essential to study this variable for urban planning. Wind speed and direction can be analyze in four ways: on-site measurements, wind tunnel, simplified computational methods and computational fluid dynamics (Broekhuizen, 2016).

On-site measurements provide a situation detailed data, but requires extensive work field, which spends time and is also subject to weather conditions, which must be local climate representative, and rainless days. They are important for the situation understanding, however its application to other scenarios prediction is limited.

Wind tunnel's tests of situation's reduced scale models allows the analysis of wind flow in the study object. Sensors can be used to obtain precise data wind speed (Carpentieri & Robins, 2015). However, two aspects must be considered: the data are obtained only in places that the sensors were positioned; and the equipment is not accessible to all, which could hinder its implementation by urban planners (Blocken, 2015).

Simplified computational methods behavior uses empirical models to estimate the wind speed in urban environments rather than using simulations of the actual physical processes (Broekhuizen, 2016). These techniques have a low computational cost, but are also less accurate. The software interfaces are more complex, which hinders their greater use.

The fourth wind analysis method is the use of computational fluid dynamics (CFD), which uses a computer model to simulate the physical processes of a particular situation. The models in CFD allows simulate various scenarios, which provides more possibilities for urban planning. The use of CFD has also been implemented more easily due to advances in computer technology (Chung & Cho, 2011).

CFD for providing a wind behavior panorama of the scene around the model in a variety of fields (Blocken, 2015), makes it more accessible in general, than the field measurements, wind tunnel experiments or simplified mathematical models (Broekhuizen, 2016). Thus, for urban planning the use of tools able to predict several scenarios facilitates and streamlines the process of decision making, such as the urban parameters definition such as height and setback areas. However to expand their use in urban planning process it is critical to validate the computer simulation from the comparison with measurement data in existing field situations, objective of this research.

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4. METHOD

To achieve the research main objective we defined methodological procedures, indicated in Figure 1.

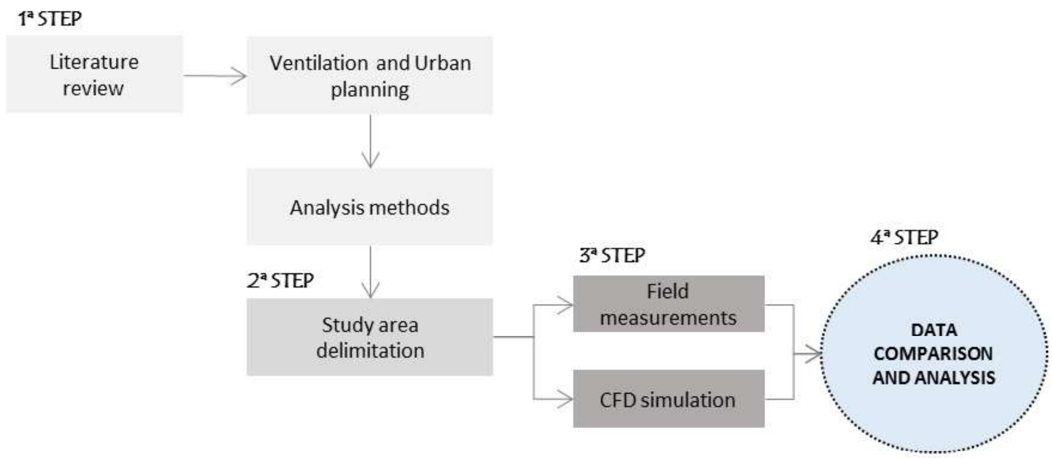

Figure 1 – Methodological procedures flowchart

The first stage was carried out a literature review about ventilation and urban planning, seeking to understand how this climatic variable is impacted by urban settings. In sequence, we conducted studies on ventilation analysis methods, to define the research methods. In second stage was defined a study area in Vitória city, for the application of measurement methods selected in the previous step, on-site measurements and CFD simulation, later the data of both methods were compared.

4.1 Study area delimitation

For analysis methods comparison we defined a territorial sampling in Vitória city, Espírito Santo's capital (Brazil), that have different build configurations. These configurations guided the location of three sampling points (Figure 2). The selected area have similarity in features as topography, network and land subdivision. The road orientation network parallel to waterfront allows to a better understanding of urban typology effect on wind.

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Figure 2 – Sampling point's indication
Source: Google Earth adapted, 2016

Point 1 is located in front of 14 floors buildings, facing the sea, with large setback areas between then. In point 2, on one side are 14 floors buildings, with large front and side clearances; the other side are buildings up to two floors, with little or no clearance front and side. Point 3 is between buildings up to 2 floors, with little or no side clearance.

4.2 Climatic measurements

The sampling points microclimate measurements were made through three portable mini-stations. The stations were positioned at 110 cm from the ground (abdomen height), according to ISO 7726 (2005), which establishes standards for physical quantities measurements. Each mini-station contains 01 portable digital thermo-hygro-anemometer, 01 windsock, 01 tripod and 01 weather shelter. The equipment specifications follows ISO 7726 recommendations (2005). The mini-stations remained in points for a 2 hours period. The times were set according the results obtained in the initial method.

The days was choose following the season representativeness criteria, ie: little cloudiness, no precipitation and minimum of 5 m / s wind speed (station's recorded, at 4 meters height). Such criteria aimed a better reception of the wind by the sensor equipment at a 110 cm height. Climate sampling occurred at 12 pm during the winter. Climate data records was registered in climate data sheets, for each point were recorded day; schedules; average and maximum speeds of sea wind (research study object).

4.3 CFD simulation

Computational fluid dynamics uses numerical methods to simulate the behavior and properties of fluid movement. The CFD software's is mostly based on Navier-Stokes equations solved at all grid's points in two or three dimensions (Carpentieri & Robins, 2015). This research used the commercial software Ansys INC Fluent 14.5 due to its wide

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application in this subject's research (Shi et al., 2015, Yuan et al., 2014). There are six steps to complete the computer simulation: geometry modeling (Figure 3); mesh definition; setup of method and analysis conditions; software resolution; and results.

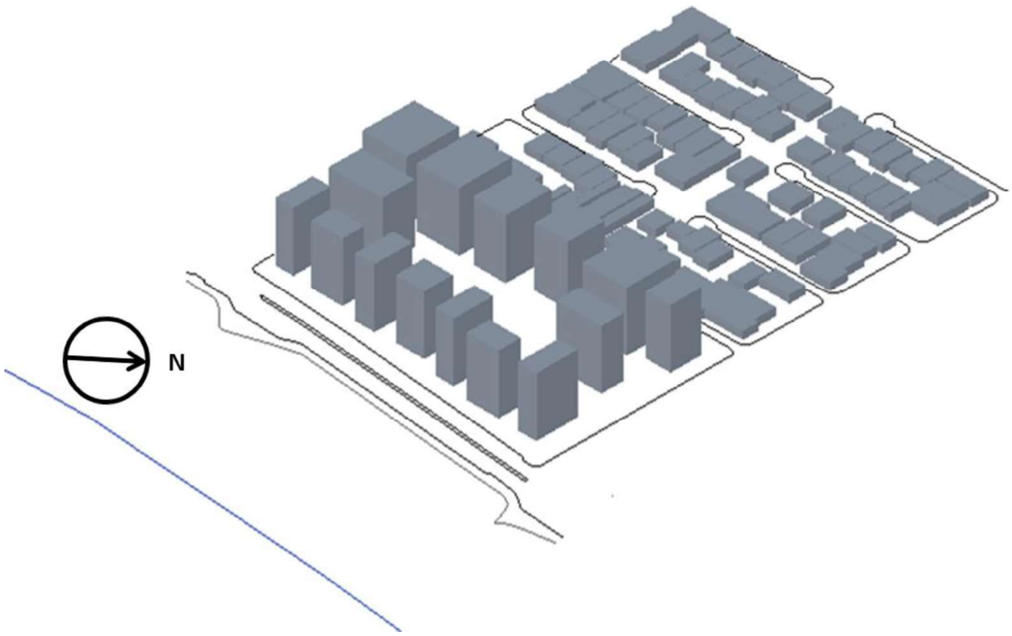

Figure 3 – Study area 3D modeling in Autocad 3D

The computational domain was a simplified version of the existing geometry because it is commonly used in urban ventilation's studies (Cheng et al., 2007, Carpentieri & Robins, 2015). The buildings were represented by simple polygons (squares and rectangles). Three-dimensional modeling was carried out in Autocad 3d and later imported on Workbench DesignModeler package, which FLUENT is part of it. Autocad was chosen for 3D due to be a well-known platform of urban planners and in that way could serve as a contributing factor to increase the use of software for these professionals.

The next step was make the mesh, which consists in the buildings and surrounding areas. We used a triangular mesh with approximately 1,300,000 knots and mesh refinement in the buildings. The turbulence was treated using the K – ε model, commonly used and recommended in pedestrian level wind analysis (Franke et al 2007; Tominaga et al 2008). Finally, we plot the results for the on-site measurements sampling points.

5. RESULTS

The data used for the comparison between the methods of analysis of ventilation, are exclusively the wind speed. For the analysis of this work it was used measurement data for the winter period, which registered the predominance of the southwest wind direction, incident perpendicular to the buildings in the study area.

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5.1 Climatic measurements

The measurements results were analysed using parametric tests (comparison between means), because in a preliminary data analysis the means proved to be more representative of the climatic conditions of each sampling point. This observation was particularly true about wind speed; because this parameter fluctuates considerably, and the maximum and minimum values masks the more frequent conditions.

Wind speeds recorded at CPTEC (Weather Forecasting and Climate Studies Center - Airport station) were higher than in sampling points (Figure 4). The airport station is located at 4 meters high in an area with few buildings, while the mini-stations were placed at 1.10 m in an area with buildings. This difference shows that the wind speed gradient reduces on approaching the ground, thus being lower wind speeds registered in pedestrian level.

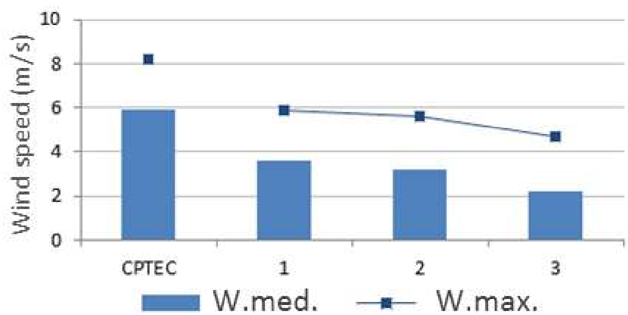

Figure 4 – Measurements 20/08/13: Wind speed

Point 1 (seafront) registered the maximum wind speed, due to the .lack of urban typology barriers in point's front. From point 1 to point 2, there was a 11% reduction of wind speed; already in point 2 to 3 had a reduction in wind velocity value about 31%. The lower reduction between points 1 and 2, was due to the superblock, which despite having tall buildings, have large distances between them which allows the wind flow between blocks. In subsequent blocks there is a difference of building typology, houses are two-story with little or no spacing between them, which creates a barrier to the wind flow.

5.1 CFD simulation

Simulation was made for the conditions set out in item 4.3. Figure 5 shows the wind flow at 1.10 meters, the same height of field measurements. The dark blue indicates lower wind speeds, and red, the highest speeds.

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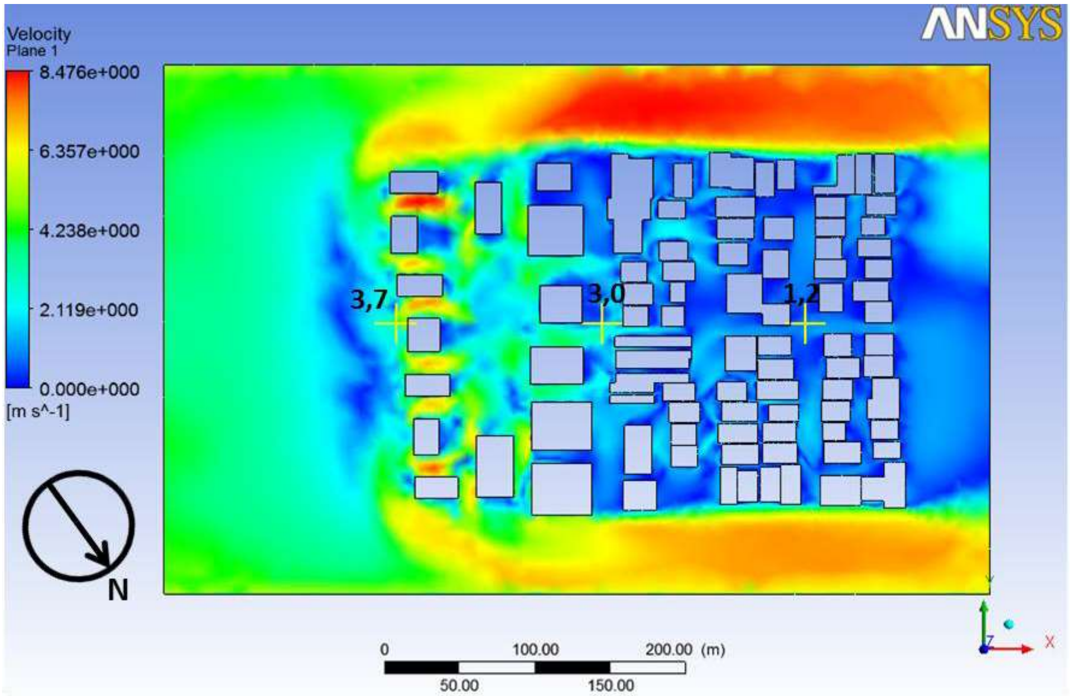

Figure 5 – Wind flow in FLUENT

The image indicates that the flow is not uniform and different types of buildings affect it. The plan in question (1.1m), little or no setback areas between buildings with two floors (behind the superblock) shows a greater reduction in wind speed.

For posterior comparison between simulation data and field measurements, 3 points where measurements were recorded, was plotted in simulation model. The wind data indicate that the higher speed of 3.7m / s was recorded in 1 (facing the sea); the next point was reduced to 3 m / s and, in point 3, the speed was 1.2m / s. This shows there was a reduction in wind speed as it enters the neighborhood blocks.

5.3 Methods comparison

The comparative analysis of data obtained in measurement and computer simulation it was noticed a greater correspondence at point 1, since it does not suffer influence of buildings ahead. The point 2 values were similar and recorded 3.2m/s in the measurement and 3m/s in the simulation. Point 3 shows a greater difference between the values: 2,2m/s in the measurement and 1.2 m/s in the simulation.

This difference is expected in comparison between measured and simulated data, as indicated in several studies (Broekhuizen, 2016), since the measurement is subject to various interference factors, such as other wind directions. Another important factor is that the wind speed fluctuates and for the simulation was used a constant speed profile, to simplify the model. Nevertheless, these issues can be adjusted in FLUENT, as the insertion of other wind direction, vertical wind profile, choosing another turbulence model.

The CFD's use in urban planning opens up a range of possibilities, as isolate variables for a particular study, prediction of future scenarios and planning new urban areas. However, measurements are important to obtain a situation climate sampling, once the results are influenced by several variables in the urban environment. Therefore, it is essential to establish the study purpose to choose the most appropriate method.

6. CONCLUSIONS

Different urban settings influences wind speed and direction. There is a growing search for quantifying the parameters that influence the wind pattern in urban areas.

In situ measurements are costly in time, manpower and money to purchase equipment. It is subject to climatic variations and the accuracy of the data recorded by professionals. The use of computational fluid dynamics software shows promise in helping the decisions that urban planners need to take, increasing the number of possibilities for studies that can be performed.

Although CFD are not widely used by city planners the possibility of use in conjunction with AutoCAD may make it an inviting tool for these professionals.

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