Natural Ventilation in a Dense Urban Tissue

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Abstract— **Wind issues in urban areas are related to seasonal demands. Architects and planners are facing difficulties in one hand with functionality and aesthetic choices and on the other hand with environmental issues. Different technologies such as CAD combined with the RANS CFD simulation method is used as an integrated package to understand and evaluate the wind flow in dense urban areas. This paper is focused on optimizing natural ventilation in a compact urban development. In this study, the air movement in the urban atrium is enhanced, by removing excessive heat and dropping the temperatures during the hot season. This paper has analyzed the wind distribution generated in an existing compact urban development. Important findings were discovered during the model's comparison. In dense urban context, the natural ventilation is not driven easily since a small amount of air is exchanged. The urban forms are capable to impact the wind by different aspects. To promote natural ventilation of dense urban tissues, different buildings high is recommended. Taking into consideration the health disorders derived by insufficient ventilation, recommendations are presented in the suggested development.**

Keywords— urban wind; building configuration; CFD; field measurements; natural ventilation

I. INTRODUCTION

Wind, as a natural force, plays an important role in dealing with urban ventilation both for indoor and outdoor living spaces. The effective distribution of fresh air is constantly needed to provide a healthy and comfortable habitat, especially for those living in dense urban contexts. In these conditions, air distribution is influenced mostly by buildings configuration. Interest in an improved quality of urban life in high-density urban areas has grown in different disciplines. Researches are focusing on immediate and long-term solutions to improve environmental quality in high-density cities. Microclimatic conditions and particularly the effect of urban wind in outdoor spaces are being investigated globally since the population living inside the urban area is increasing dramatically (United Nations 2010) [1]. In the recent year's planners are developing modern spaces with different configurations and materials, far from vernacular architecture which mixed in harmony people, buildings and climacteric conditions.

People's comfort also depends on the wind condition, which is strongly guided by man-made barriers and the urban spatial morphology (Hala et al. 2018) [2]. Many contexts suffer from insufficient ventilation due to obstacles in and outside the domain. Especially high-rise buildings affect various aspects of the urban spaces' underneath. Also, Durgin and Chock, (1982) revealed that wind condition is also related to the performance of buildings in an urban area [3]. Kazim et al. (2014) [4] points out the importance of studying beforehand the surrounding buildings to obtain an efficacious ventilation system. Also, Hala (2017) [5], stated that the direction of breezes is influenced by surrounding forms and could differ from the prevailing wind.

A. Seasonal demands

However, wind issues in urban areas are related to seasonal demands. The winter strategies are focused on protecting buildings, walkways, entrances, and outdoor spaces from wind at high velocity. Specific studies are focused in winter such as Kusaka, et al. (2018) [6], insist that sunny public spaces in combination with reduced wind speed can prolong the duration of use of outdoor public spaces in Sapporo. Summer targets on the other hand, aim to prevent heat gain and to stimulate the ventilation of breezes and evapotranspiration (Newman 2005) [7]. Most of the time, insufficient ventilation relates to high temperatures. Hence, Yang and Clements-Cromie (2012) [8], emphasize that based on the local and seasonal demands, architects should take advantage of natural forces, particularly the wind, consequently, equip their designs with towers and atriums to better ventilate occupied spaces. The wind issue becomes important particularly to new development areas. Architects and planners are facing difficulties in one hand with functionality and aesthetic choices and on the other hand with environmental issues. Outdoor public spaces are invented for recreational activities, for people to relax, and those who like to interact. Nonetheless, a poorly ventilated area would reduce the time spent in it. Also, Bosselmann and Arens (1990) [9], revealed the existence of an unpleasant environmental condition in correlation to the urban context in the city of San Francisco. They pointed out the urban design problems into the regional and seasonal climatic elements. Many other researchers such as Taguchi et al. [10] classified the public space according to human comfort.

B. *Computational tools*

Even though it is invisible, wind flow can be evaluated on-site with the help of simple instruments. These assessments can address different strategies related to insufficient ventilation in an urban context. Though, on-site analysis and wind tunnel tests present insufficient information when comparing to computational fluid dynamics (CFD). That is why for the last 50 years CFD methodologies offered a better understanding of the air motion (Blocken 2014) [11]. Many authors uphold the CFD as a method to address design-related approaches such as Reiter 2010, who constantly recommends the usage of CFD to analyze the wind flow in environmentally sensitive domains [12]. Stathopoulos (2002) [13] recommend this method as an appropriate one for pedestrian levels wind, dispersion of pollutants in the near-buildings, urban ventilation, etc. Castro and Graham (1999) [14] doubt about CFD as an accurate method, especially in cases that new problems are not verified beforehand. They sustain that CFD engages substantial quantities of computation even for simple simulations. The paper evaluates the natural ventilation in the existing building layouts using CFD.

C. *Case study*

Albanian cities are affected by rapid expansions resulting many times in dense developments, far from being sustainable designs. Open spaces are diminishing progressively because of the high demand for dwelling. The metropolitan district is becoming each passing day more expensive, giving space to tall buildings and concrete walkways. This is the case of a residentiary area in Tirana (Fig. 1) in a newly developed zone. It results among the densest area of the city, concentrating numerous inhabitants and repeatedly is criticized for being intensely populated. The early buildings were starting by the beginning of 2015, and yet they are under construction. The eight-story buildings accommodate different functions such as housing, offices, parking, shops and so forth.

Figure 1: Photos taken from the current urban development

D. *Problem statement*

The building design teams didn't provide any environmental study of this area. Therefore, our concern toward a possible problem with urban planning has grown. The spatial atriums generated mostly for recreational purposes may present insufficient wind ventilation, and their inhabitants would have a lower quality of life. Achieving sufficient ventilation in a complex urban area may become a real challenge. The wind usually refers only to the horizontal air flow, even though it has a vertical weak component (Crosbie et al. 2008) [15]. The urban design offers many closed perimeters, difficult for the wind to penetrate in such enclosed atriums. This paper is focused on optimizing natural ventilation in a compact urban development. In this study, the air movement in the urban atrium is enhanced, by removing excessive heat and dropping the temperatures during the hot season. Taking into consideration the health disorders derived by insufficient ventilation, recommendations are presented in the suggested development.

II. METHOD

Tirana Municipality provided some designs for this urban development. We were able to use these papers in order to draw the three-dimensional (3D) models in a computer aided design software (CAD) and later transferred in CFD software. These models were built in 1:1 scale. They preserve the exact building geometries. The 3D model was refrain from many facade details such as lodges, balconies, terraces, canopies, etc. We consider them as incapable of affecting the wind flow due to their insignificant dimensions in comparison to the eight-story building.

A. *The simulation parameters*

The RANS turbulence parameters were two; one is focused in the transport equation of the kinetic energy k and the second controls the transport of the dissipation rate Ɛ of K. The turbulence parameters for the model were: Model of turbulence=k-epsilon; Turbulent kinetic energy=0.015; Turbulent dissipation rate Ɛ = 2.5471E-06 and Specific Dissipation rate ω = 0.00188671. The wind tunnel parameters were: Kinematic Viscosity:1.5e-005m^2/s; Density 1.25kg/m^3. The calculation is made based on: Numerical solver: Open FOAM, Maximum number of iterations: 500, Convergence criterion (P-Residual) = 0.001.

Wind parameters for the chosen area was provided the Weather Spark website. This website represents the mean wind data determined over time for Tirana city. Over the year, the windy days are more frequent along late Autumn, Winter, and Spring. The windier months are October to April at an average wind speed of (3.1m/s). Velocity: 3m/s was chosen for running the simulation. This speed coincides almost half of the year (5.6 months), in the selected site. Direction: The northwestern wind direction was the only one chosen for the simulation. According to Weather Spark, the wind is most often from the north*east* for *8.9 months.*

B. The simulation settings

Two models were built for the simulations. The first model matched the actual exact situation. The second simulation was optimized by removing one of the building, considered to obstruct the wind flow. Both simulations were tested at the same wind velocity 3m/s. Since the urban design is almost completed, we could conduct several field surveys. With the help of anemometers, we could obtain in-site measurements. We were able to compare the CFD results afterwards with on-site investigations (Fig. 2).

III. RESULTS

A. CFD settings

The CFD used 914,154 cells and 1,0741,758 nodes. This grid resolution has been accurate and efficacious in terms of computational time. A coarser grid was used prior to the final simulation. However, these results were not taken into consideration. All the horizontal results were taken 2 meters above the ground. Hence, the results will be used as a referring point for the pedestrian level. Apart from the horizontal values, we were able to place also vertical plans to have a better evaluation of the entire area.

CFD parameters were: Dimensions: Dx=2,770m; Dy=1,975m; Dz=261m; Original model drag force sum: Fx=804kN, Fy=-36kN, Fz=1695kN. Simplified model drag force sum: Fx=792kN, Fy=-34kN, Fz=1649kN. Flow parameters were in the following terms: Inlet velocity 3m/s; Kinematic viscosity 1.5e-005m²/s; Density 1.25kg/m³. The second simulation runs the same wind velocity. Almost every model parameter and wind characteristic remain the same despite the absence of one building.

B. Simulations results

The first simulation that coincided with the actual design generated the highest wind velocity of 4.22m/s despite the prevailing wind speed of 3m/s, (Fig. 3). The area affected most by the high-velocity wind was discovered in the gaps between the buildings. Is there where the flow sections are reduced giving room to faster air exchange. In the open field, the situation appears to be much calmer than the external gaps. Dangerous high wind velocities don't appear in the summer simulation parameters. The wind velocity ratio varies from 0.2m/s to 1.8m/s.

By removing one building, considered an obstacle for the flow in that direction, the wind velocity was significantly changed. We could get an increased velocity to more than 2m/s and it dominates beyond 70% of the area, right after the removed building (Fig. 3).

Placing this building perpendicular to the flow refrain a large amount of air from accessing the area.

The situation in the closed atriums substantially changed. In the optimized scenario the air mass in the atrium's exchanges in a higher volume, (Fig. 4). Wind speed ratio, inside the atrium area, varies from 0.5m/s

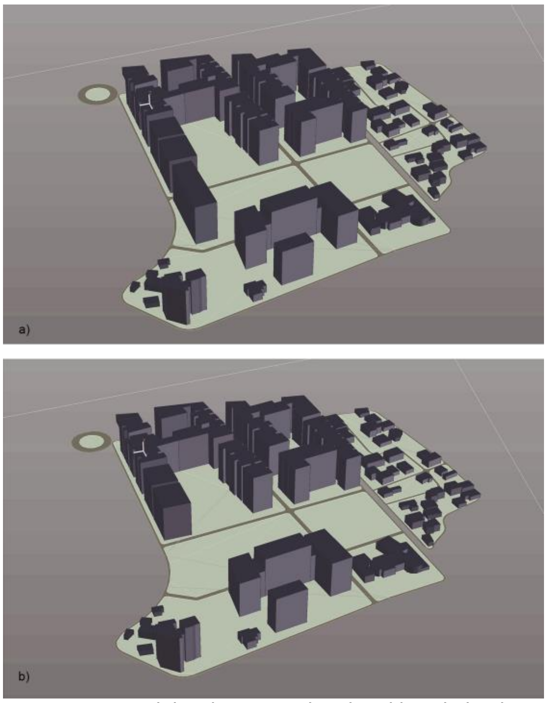

Figure 2: CAD models; a) current situation; b) optimized model

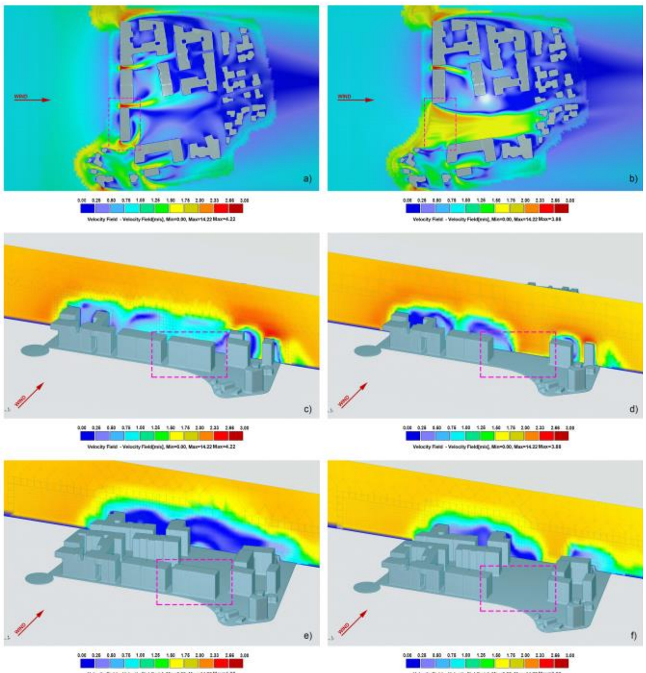

Figure 3: a);c);e) velocity field - current situation; b);d);e) velocity field - optimized model.

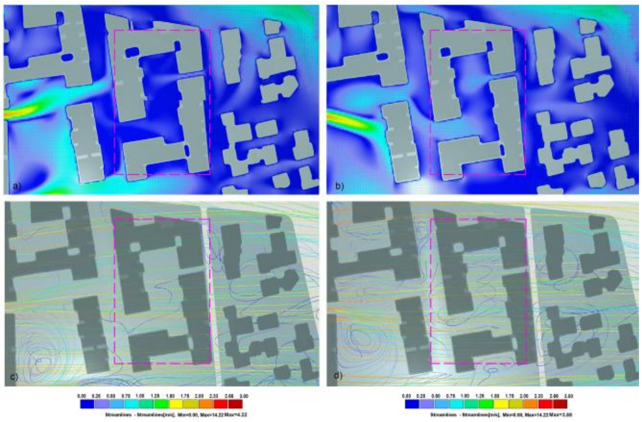

Figure 4: a) velocity field - current situation; b) velocity field - optimized model; c) streamlines - current situation; d) velocity field -

to 1m/s and it is considerably higher compared to the existing situation where the speed is only 0.25m/s 10% of the atrium's area. This value was also confirmed by in-site investigation and the anemometer measurements. The reading for this area was 0.22m/s on a moderately windy day with a prevailing wind of 2.87m/s.

There is an optimized situation also in the individual house territory. By removing one of the building we can open the flow corridor and the air can easily distribute in the area, (Fig. 5). In this case, no in-site investigation would be correct, since the urban design is already completed.

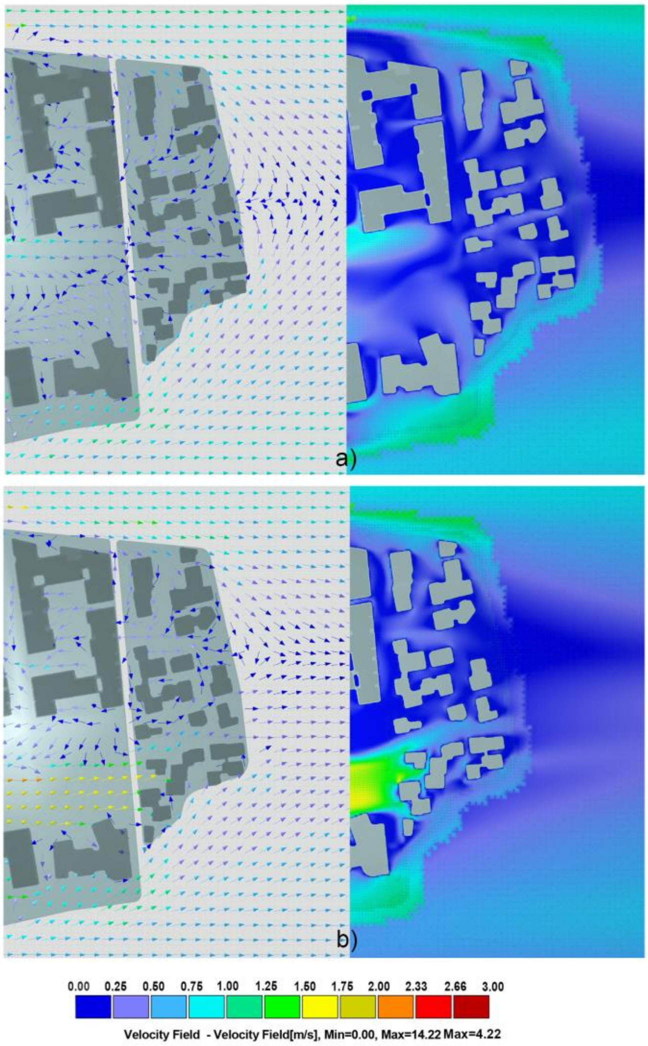

Figure 5: velocity vector and field a) current situation; b) optimized

The uniform high in the constituent buildings does not simulate any down-draught effect of certain buildings. The down-draught effect is not present. Additionally, this effect could be found in the outer buildings of this urban design.

In the pressure field graphs, results show the maximum dynamic pressure in a range starting from +53.1Pa to a minimum of -120.1Pa (Fig. 6).

The lowest pressure field could be found in the optimized model. The closed models present a higher pressure in the external buildings. Considering that the second simulation presented a broken perimeter, the pressure range in the open field changed from -18Pa to -13Pa. The surface pressure charts confirm the above result but to lower pressure values, respectively +52.8Pa to -97.4Pa.

IV. Discussion

This paper has analyzed the wind distribution generated in an existing compact urban development. Important findings were discovered during the model's comparison. Our concern toward a possible problem with urban planning was confirmed by comparing two models. The optimized model provided better ventilation in contrast with the current urban design, mostly because of the elimination of one building, considered an obstacle for the wind flow in that direction.

The atriums created mostly for recreational purposes presented insufficient wind ventilation, and their inhabitants would have difficulty in fresh air exchange. The air movement in the urban atriums is enhanced only by removing a building positioned across the main wind flow. Because of this action, we might be able to remove excessive heat much faster and drop the temperatures during the hot season. A closed atrium surrounded by tall buildings is not advantageous in terms of natural ventilation. It is

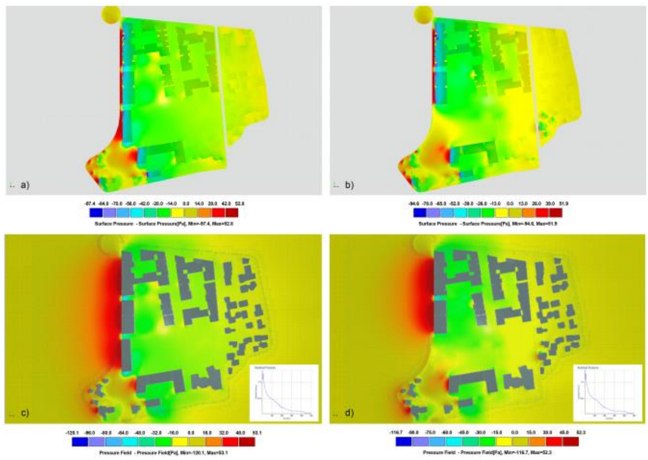

Figure 6: the creation of vortexes; a); b) current situation; c); d) optimized model

essential to point out that these areas are not appropriate for underground parking ventilation ducts placement. Their presence would worsen the air quality in these sensitive areas and would obstruct the ventilation in the underground parking. In every area that the wind reduced the velocity, it could be the risk of insufficient ventilation. The air circulation depends also by the wind velocity at a certain time (Bucza and Sumorek, 2017) [16].

High-speed wind currents are created in the gap mostly by parallel facades and small sections. The wind gains speed in the gaps due to the high pressure created in the building's facades (Hala, 2017), [2]. In a windy day, not rare for the area, the tolerate wind speed generated in the gaps would be 4-5m/s. More than that it would be difficult for people traversing, jogging or running but not comfortable for people sitting or resting (NEN 8100, 2006); (ASCE, 2003) [17] [18]. Mitigation strategies would be recommended in order to protect these spaces, such as trees and other floral elements.

Vortexes are present mostly in the current urban design (Fig. 7a), since the air is stuck in closed shapes. Small vortexes are also present in the optimized model but in an insignificant velocity (Fig. 7b). These effects probably are found in all open fields, which are surrounded by high barriers.

Achieving efficient ventilation in a complex urban area may become a real challenge. The wind is very difficult to be predicted also in the quietest environmental condition. Orlandi (2000), pointed out that the air mass moves over an urban context in an unpredicted way and this is a complex fluid flow phenomenon [19]. Inspecting Fig. 6c-d, we could find a faster movement of the air above the ground because of the Venturi effect (Li et al. 2015) [13].

Relying on an overall evaluation of wind engineering, we have found the following explanation for insufficient ventilation in some parts of the current urban design. Taking into consideration the health disorders derived by insufficient ventilation [reference], recommendations would help to create a

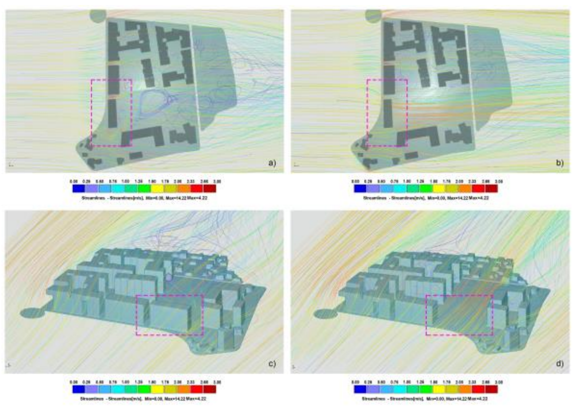

Figure 7: the creation of vortexes; a); c) current situation; b); d) optimized model

better living space. The closed perimeters in urban contexts do not promote natural ventilation since a small amount of air is exchanged from and outside the atriums. According to Yang and Clements (2012), natural ventilation is acquired by the air density difference of the inner and outer environments. With no communication between the environments, the air is obstructed so the ventilation would be worsened.

Also, different buildings high would help to improve the ventilation of certain urban areas due to the downwash of the wind through the building facades. This effect would be analogous to the wind towers '*bagdirs*', an antique element of Islamic architecture mentioned also by Yang and Clements (2012) [8]. The wind tower enhances air circulation in many ways. The constant building high would not enhance the air circulation because no down-draught effect would be generated from the wind.

The building demolition as a method to release the wind corridors would be an extreme scenario hence, simple mitigation strategies are typically recommended to improve air ventilation in the existing urban contexts with high density. The implementation of air deflectors such as canopies, roofs, would certainly have an impact in enhancing the natural ventilation inside the dense areas. Other research must be done such as controlling the building materials implementation and tree planting in order to reduce the excessive heat and dropping the temperatures during the hot season. However, wind issues in urban areas are related to seasonal demands. These strategies can both be used during winter and at the same time to enhance ventilation during summer.

V. Conclusion

This paper is focused on optimizing natural ventilation in a compact urban development. In this study, the air movement in the urban atrium is enhanced, by removing excessive heat and dropping the temperatures during the hot season. The studied area was surrounded by tall buildings, and this raises our concern about insufficient ventilation inside the urban design. The architectural proposal did not provide any study focused on the wind flow therefore, we have been able to develop CFD as a method of evaluating the wind flow in the area.

In-site investigation was able since the urban area is almost developed. But the information retrieved from the CFD is more detailed and accurate in comparison to other techniques. The in-site measurements serve only for confirmation of the information received from CFD. Different technologies such as CAD combined with the RANS CFD simulation method is used as an integrated package to better understand and evaluate the wind flow in dense urban areas.

In dense urban context the natural ventilation is not driven easily since a small amount of air is exchanged. Hence this paper demonstrated the difficulties the closed urban forms have toward efficient natural ventilation. These shapes present intimacy and offer protection from strong wind, especially during winter, but they are disadvantageous in terms of excessive heat dissipation and temperatures dropping during the hot season.

The urban forms are capable to impact the wind by different aspects. To promote natural ventilation of dense urban tissues, different buildings high is recommended. The down-draught wind effect would inject the fresh air at the pedestrian level at a higher velocity.

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