Journal of Fundamental and Applied Sciences

ISSN 1112-9867

Available online at http://www.jfas.info

Research Article

A NUMERICAL AND EXPERIMENTAL STUDY OF URBAN GEOMETRY'S CONTROL OF WIND MOVEMENTS IN OUTDOOR SPACES. CASE OF A HUMID CLIMATE

S. Bouketta*, Y. Bouchahm

Laboratory of Bioclimatic Architecture and Environment A. B. E, Institute of Architecture and town planning, University of Constantine, Algeria

Received: 01 October 2018 / Accepted: 25 December 2018 / Published online: 01 January 2019

ABSTRACT

Many studies have shown the impact of urban geometry on thermal comfort in outdoor spaces, but few of them have addressed the control of adverse wind effects in urban humid areas. This work deals with this specific context. It aims to highlight the role of the geometry of urban spaces in the control of the wind, mainly in the city of Jijel (Algeria), where wind is the essential element to be reckoned with. It is shown concretely into in-situ measurement campaigns (taken in winter 2016 and summer 2017) during which microclimatic parameters were recorded simultaneously for tow case studies with distinct geometries spaces between the U-shaped and L-shaped buildings. More precisely, the first step is to identify the most important geometrical parameters and then describe the wind behaviour by numerical simulation with the help of the "Envi-met V4" software. The results show that the H/w ratio is the geometrical parameter to take into account in order to control the wind.

Keywords: geometry; outdoor space; wind control; measurement; simulation.

Author Correspondence, e-mail: samirabouketta@gmail.com
doi: http://dx.doi.org/10.4314/jfas.v11i1.26

1. INTRODUCTION

The urban development of towns and cities shows diversity in the conditions of their creation and their effects: the urban forms produced their utilities and purposes [1]. These urban forms are not the same; they are set up in different ways, coming out with urban spaces that often have no link with the climate and its effects [2]. Indeed, the wind is one of the components that have to be taken into account. It is a perceptible enough element of the urban microclimate for the citizen; it can be a source of coolness and ventilation in summer, or a source of nuisance in winter, causing the citizen to feel uncomfortable outdoors.

Moreover, the wind often becomes responsible for the type of urban microclimate. The reduction of its speed by the presence of buildings and the lessening of the effect of external natural ventilation are among the parameters which contribute to the intensification of the phenomenon [3]. According to [4], the urban wind, in particular, can be controlled and modified by the urban forms and their geometries. The orientation of the streets, the profile of the building blocks (form, height, size), their density, their orientation as well as their shape, are then the geometrical parameters that have a direct impact on the wind flow in an urban setting[5]. From what precedes, the following question comes up: to what extent then can urban space geometry controls the harmful effects of the wind?

Several research works have pointed to the role of the layout of urban space in the control of wind-induced hurtful effects. Because of the fluid character of the wind, the most determinant geometrical factor in controlling the flow of air is free-space geometry. Put otherwise, it is the H/w urban profile (the ratio between the average height of the space and its width) which strongly determines le level of sheltering from, and exposure to, the wind in the urban entity.

In this way, some research interested to study the passive exterior ventilation performances in modern urban contexts [6].

It schow that wind flow diminishes in its contact with the buildings, canalized by larger urban canyons, then regains strength in the open space free flow. This would allow wind circulation to improve at certain places and maximize thermal comfort, while creating whirlwinds. These whirlwinds are generally created in built-up corners causing some inconvenience to pedestrians. Another study [7] focused on the geometry of the street (length “L”, height “H”, width “w” and orientation of the street) and its impact on the behaviour of the wind. This study shows that the length and lack of symmetry of the street have an influence on the intensity of the air draughts: the horizontal flow is more important in a long, narrow canyon street than in a shorter, less ‘profound’ street. Moreover, for a long and symmetrical street, the results yield an important canalizing phenomenon leading to a direction that is always parallel to the axis of the road even when the wind comes sideways. Furthermore, the length of the street seems to have less effect on the airflow mechanism in an asymmetrical and long street than it has in a symmetrical street.

The importance of the third dimension has been made obvious in other work in which the effect of the height of the buildings on the wind flow is tested in a Malaysian urban arrangement and proved that a progress pyramidal outline of the heights of the buildings scattered the wind evenly and made it possible for it to reach the lee side of every building [8]. This improves natural ventilation and thermal comfort at the pedestrian level. For their part, [9] took an interest in evaluating the pedestrian comfort wind-wise and ensuring their security against the harmful effects of the wind in urban areas with the help of numerical simulation.

The aim of this research is to demonstrate the role of urban geometry in controlling the harmful effects of the wind in the urban space in a humid climate, like the one in the town of Jijel (Eastern Algeria).

2. CONTEXTUAL PRESENTATION OF THE STUDY

By its position on the North-Eastern Algerian coastline, Jijel offers all the climatological characteristics of the maritime Mediterranean regions [Fig.1]. It is considered as one of the rainiest areas of Algeria.

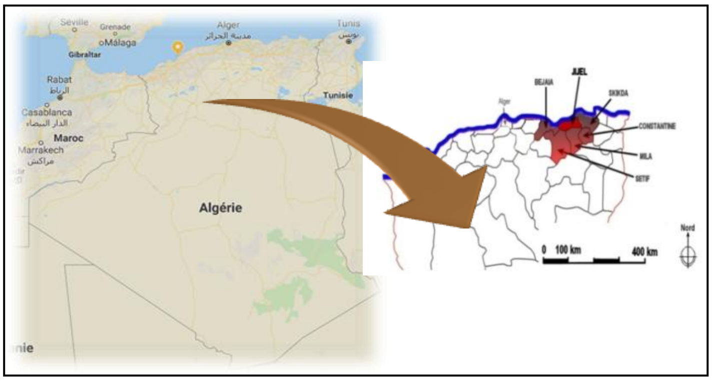


Fig.1. Situation of the town of Jijel

Its Mediterranean climate is rainy and mild in winter, hot and moist in summer. From the Fig.2. (A-B), the interpretation of the meteorological data of the town of Jijel for the period from 1999 to 2015 yields what follows:

1. The hot season stretches from June to September with maximum temperatures standing at between 28.2°C and 31.8°C. The daytime and night-time monthly temperatures are rather low, the highest showing 26.3°C, with a maximum at 31.8°C and a minimum at 20.6°C. The relatively cold (mild) season goes from October to April, with temperatures between 16.2°C and 20.9°C. In January, the coldest month, the temperatures reach their minimal value at a monthly average of 11.6°C, the maximum being 16.2°C and the minimum 6.2°C [Fig 2. (A)].
2. As for the air moisture, the relative humidity rate is very high during the two periods: in winter, the relative annual average is 78%, recorded in January; in summer, the highest relative humidity rate is 77%, recorded in May [Fig 2. (A)].
3. The compass card shows that, in winter, the prevailing winds are North to West. Wind speeds between 4 to 6m/s and 6 to 8m/s are the most frequent and take a North to North-West direction. The frequency of strong winds is 1% on a N to N-W direction, while that of the quieter winds is 50% [Fig 2. (B)].

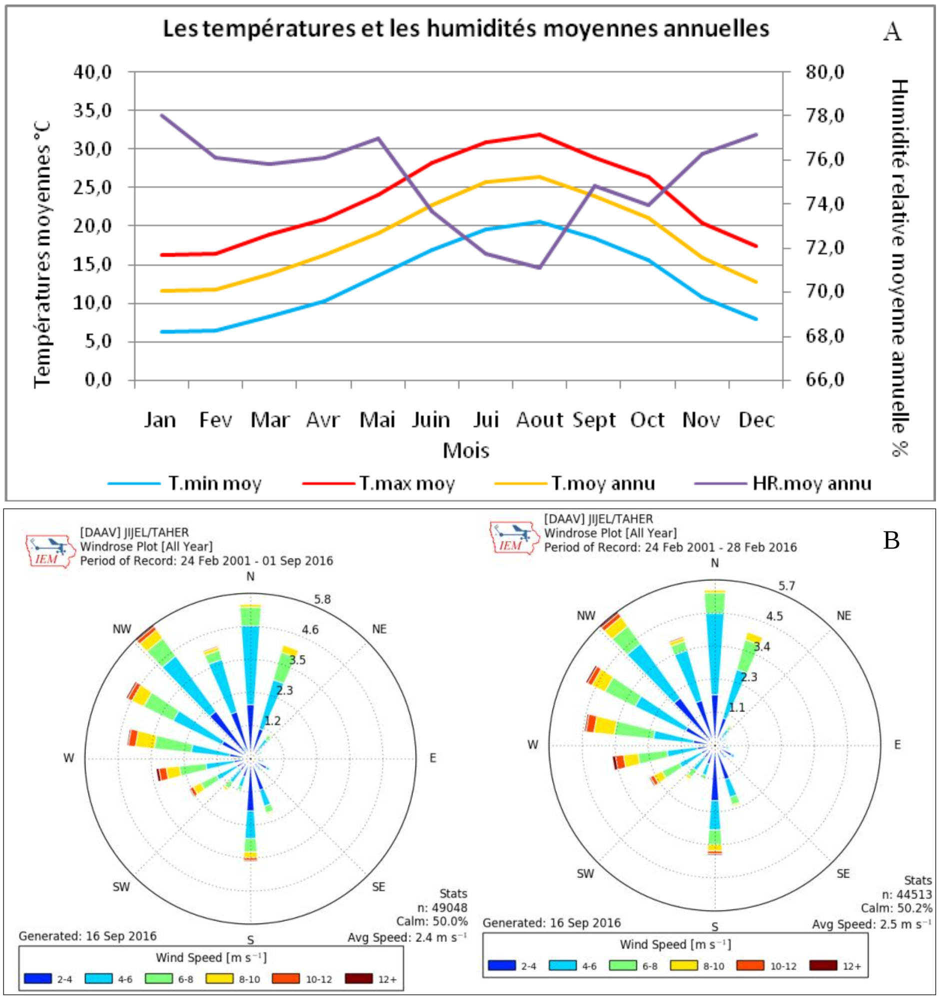


Fig. 2. Graphic interpretation of meteorological data.
A: Air température and annual average relative humidity.
B: Annual and monthly (for February) compass card.

3. WORKING METHODOLOGY

In order to stick to the planned objectives, this piece of work has been divided in two parts: a fieldwork, by doing onsite measurements and investigations, and a numerical simulation using the software. This has been done after choosing the study case.

3.1. Choice of a study case (sampling)

The urban space is part and parcel of a town and henceforth offers distinctive features of form, usage and style which all offer the citizens new ways of leading a life of well-being and conviviality. It is perceived at different levels which correspond to a whole network of roads, places squares, public gardensand to all the outbuildings. It is determined not only by the climatic conditions but also by the geometry of the built-up space around it.

In this research, the interest is on the external space that lies between the buildings, also known as the unbuilt interstitial space. This outdoor space is considered as the supporting element of the urban quality of life and that includes notions of identity, comfort, values as a going concern, accessibility and conviviality, which are so many notions to be taken into consideration for any conceptual approach. However, in the town of Jijel, the outdoor space is badly appraised by the citizens. This refers not only to the social dimension, but also to the climatic concern linked to the parameters of wind, humidity and temperature which have an effect on the perception of outdoor space, especially in winter.

For the choice of the study case, the typo-morphological approach has been adopted as a means for analyzing all the blocks of flats for collective accommodation that exist in the urban area of Jijel in order to study the space left between these buildings[Fig.3]. All the blocks of flats had to be recorded and classified step by step. Therefore, several successive classifications were carried out in order to bring out the most representative type [10]. State of the art classification criteria have been retained for the different phases [Table 1].

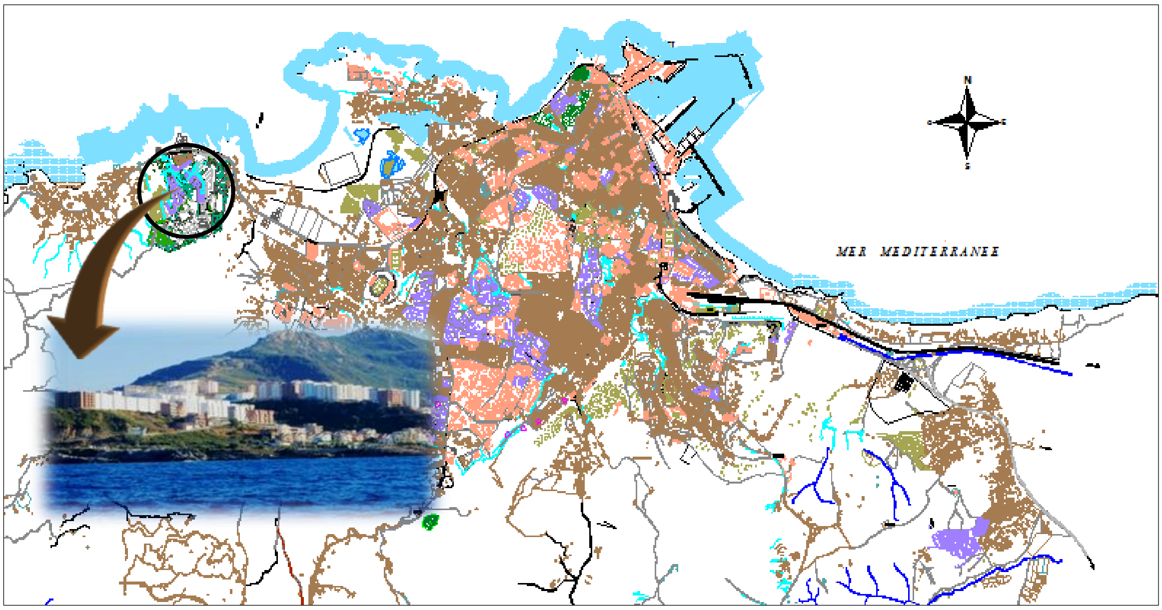


Fig.3. Identification of collective accommodations (in move color)

Table 1. Indicators of Classification

Criteria and indicators of classification	
1st classification: indicators of a general order	• Distance from the sea to assess the effect of the breeze • Altitude in relation to the sea level • Characteristics of the microclimate (presence of vegetation,etc.) And so, oppositions appear, such as: old/new, equipped/ empty, planted/ naked, vegetal/ mineral, large/ narrow, high/ low, open/ shut, aired/ stifling, sunny/ shady, etc.
2nd classification: morpho-physical indicators	• Density of built-up area • Visual atmosphere (quantity of shade, foliage movement, glare, lighting contrast)
3rd classification: geometric indicators	Morphology of the place through the physical elements among which the buildings. • Geometry of the whole group (shape, dimensions, configuration and geometric form) • Urban porosity • The form of outside space generated by a group of H/w buildings

Several geometrical configurations appeared, giving substance to the study. Up then rise linear, parallel, straight-lined, U-shaped and L- shaped orderings, with the juxtaposition of several buildings. As for the outdoor space, it presents a variety of forms and functions, from playgrounds, green open spaces, to pedestrian subways. From this variety, two geometrical forms have been retained [Fig.4], which are widespread in the old building patterns: the U shape and the L shape, which are to be found at the new residential area of Mezghitane Mountain west of Jijel.

Fig.4. Case studies selected

3.2. Investigation and measuring campaign

Measurement is a reliable tool for quantifying climatic parameters. The aim of the set of measures for the study case is to emphasize the microclimatic variations of the outdoor space. In the first place, the microclimate variations of the study in question have to be determined by measurement and then compared with the references of the local meteorological station. Second, the interaction between the behavior of the wind and the different geometries of the outdoor spaces from carefully selected measuring points, according to several criteria; to wit the type and form of the outdoor space, the direction of the prevailing winds, the presence of vegetation as well as the presence of ventilation corridors, in order to single out any aerodynamic deviations.

The measures were taken with the help of a portable multifunction LM-8000 model. This apparatus is conceived to acquire four dimensions; air temperature, relative humidity, wind speed and lighting (portable anemo-thermo-hygro-luxmetre).

The measures were taken on the 28th of July 2016 for the summer period and on the 16th of Febraury 2017 for the winter period. Nightly hours have been set aside. The bi-hourly measures which went from 8 a. m to 6 p. m for the two seasons were taken only in daytime, when the pedestrian circulation is important.

3.2.1. Results of the investigation

3.2.1.1. Evaluation of the geometric effect on the temperature and the speed of air during the winter period

Point A records a temperature of 20°C which remains higher than that of the two other point B and C (respectively 19.9°C and 20°C). As a matter of fact, the space width of places B and C is inferior, compared with that at place A, which reduces the quantity and penetration of the sun rays received and increases discomfort in the places [Fig.5]. Dealing with the same subject, [11] showed that the increase of the H/w ratio leads to a higher percentage of shade and hence, to lower temperatures.

The site of our study case is very close to the sea, at an altitude ranging from 60 to 110 metres. Therefore, the effect of humidity has been ascertained because the value corresponding to a high rate of humidity was recorded at point C, then at point B and A (51.2%, 51% and 51.1%). However, the effect of the altitude on the wind speed was not felt throughout this measuring session until nightfall. In fact, the measured wind speeds fluctuate between 1 and 3 on the Beaufort and did not reach the wind-induced threshold of discomfort tolerated in the urban area at 5m/s.

Furthermore, the behavior of the wind at figure 5.2 shows that there exists an enclosed space along with open spaces. Indeed, this change in behavior is due to the geometrical layout of the free space between blocks formed by the built-up surface (the spaces between the blocks of buildings). The most important wind speed, recorded at point C, is 2.4m/s at 2 p.m. This point is subjected to a canalizing effect towards the prevailing winds because of the U-shaped arrangement of the buildings [Fig.6]. The presence of the passage between the blocks resulting from the reduced “prospect” (the minimum authorized distance) has exacerbated the wind flow. Similarly, a speed of 2.2 m/s was recorded at the same hour for point B which is enclosed in a tight intersection of L- and U-shaped lines of building blocks. Point A is not face to the wind, which tempers its speed down to 0.8 m/s. On this spot, the gap between the buildings is more important, compared to that of the two others.

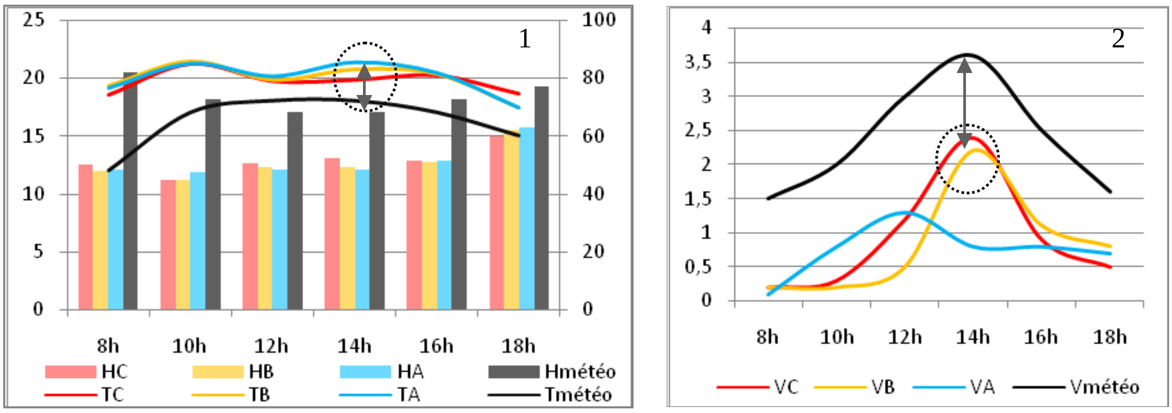


Fig. 5. Microclimatic variations in winter. 1: air temperatures and relative humidity. 2: wind speed.

Fig. 6. Wind flow between buildings in winter

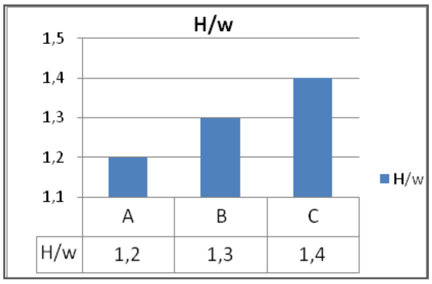


Fig. 7. Values of the H/w ratio

3.2.1. 2. Evaluation of the geometric effect on the temperature and speed of air in the summer

The figure 8 outline shows a noticeable gap in the readings, which can reach 4°C between the different measuring points during the day. The maximum temperature recorded at the meteorological station is 32°C at midday, whereas the maximum temperature on site at the same time is 36°C at point C (ΔT=4°C), followed by pointsA and Bwith respective values of 35.3°C and 34.7°C [Fig.8 (1)]. The solar radiance reaching these sites is reduced according to the opening of the "sky view factor" (SVF) at points A, B and C equal to 0.4, 0.2 and 0.5 respectively; that allows temperatures at point C to increase and those at A and B to decrease. As for the origin of the wind, it comes from a North-Eastern direction [Fig.8 (2)]. One observes that point A is highly ventilated in view of the recorded speeds which increase after midday; point C moderately ventilated and B poorly ventilated. This is in fact due to the combined effects of the geometry (the corner effect) with the impact of the wind (against the wind). Indeed, the orientation of the buildings in relation to the wind is decisive since it leads to the amplification or reduction of the infiltration rate. This applies to B and C which being badly oriented in relation to the origin of the wind, are sheltered from it, and that creates bad ventilation at point B [Fig.9].

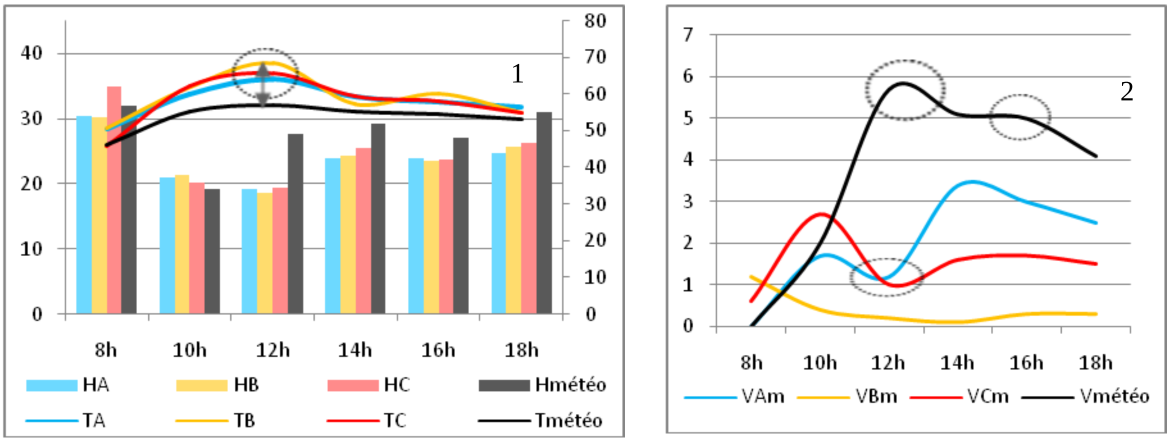


Fig.8. Microclimatic variations in summer. 1: air temperatures and relative humidity. 2: wind speed

Fig.9. Wind flow between buildings in summer

3.3. Numerical simulation

From the results of the investigation, it follows that the behavior of the wind varies according to the geometry of the outdoor space which plays a key role in the control of the wind movement. Controlling the movement is only possible by optimizing the geometry at points A, B and C. Numerical simulation turns out to be necessary for qualifying the movement of the wind at the level of the three points. It will help check the results of the investigation and propose a modification or improvement of what exists.

A whole range of numerical simulation tools are pro posed nowadays in the framework of urban modelling. Among the tools which help to provide for a climate modified by the presence of a town, one finds a very limited number of models that could reproduce, to a sufficiently good degree of precision, all the complexity of the urban climatic system: simultaneous and interactive calculation of the radiative, thermic, aerolic assessment on several scales, taking into account the transfers between the air, the vegetation, the buildings and the floor [12]. This led us to single out ENVI-met 4.3.0 (licensed) in the present context of this research work [Fig.10]. There is a drawback, however: calculation takes a very long time, even with a powerful adding machine.

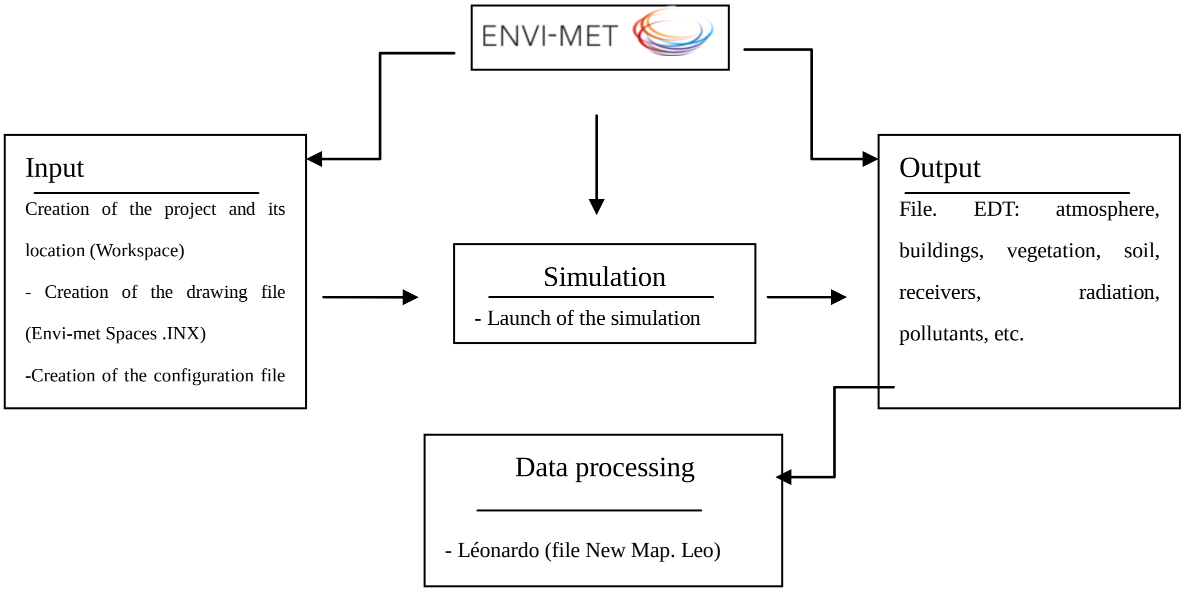
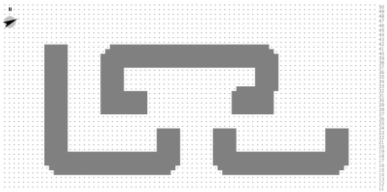
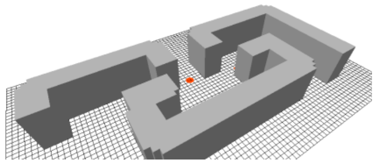
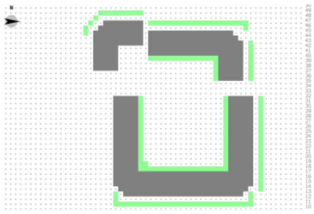
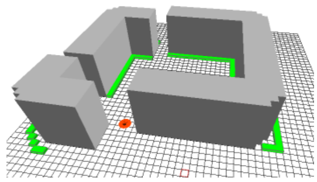


Fig.10. Software structure

3.3.1. Simulation procedure

The simulation was carried out in parallel with the periods chosen for the investigation. The study cases were carefully drawn up according to a convenient scale. Dimensions and heights of the buildings as well as the vegetation were reported in order to reproduce the reality of the site [Table 2]. The gathered parameters will be analysed by ENVI-met and read par Leonardo.

Table 2. The study cases reproduced by software – 2D, 3D drawing

		Dessin en 2D	Dessin en 3D
Cas d'étude	A et B		
	C		

3.4. Simulation results and discussion

3.4. 1. In winter

The results of the simulation on the speed of the wind in winter [Fig. 11] show that the highest speeds were recorded at point A, followed by B and then C for which weak speeds were noted, and that makes A highly exposed to the wind and B and C protected from it. This was not the case when measures were taken on site. In fact, a comparison of the simulated with the measured wind speeds shows that B kept just about the same speed and that the variation lies with A and C. This is due to the orientation with regard to the wind on the one hand, and to the geometry on the other.

The ENVI-met software considers only one direction during the whole period of the simulation, when in fact the wind is highly changeable direction wise. From the geometrical point of view [Fig. 12], the layout of the buildings at C has created a shut-in indoor space so that winds are deviated all around. In spite of the reduced H/w, the wind has not been funnelled into the enclosed space by the simulation. Indeed, the geometry of points A and B is seen as being more ventilated, the wind canalized between the parallel rows of buildings, which explains the increase of speed at these two points.

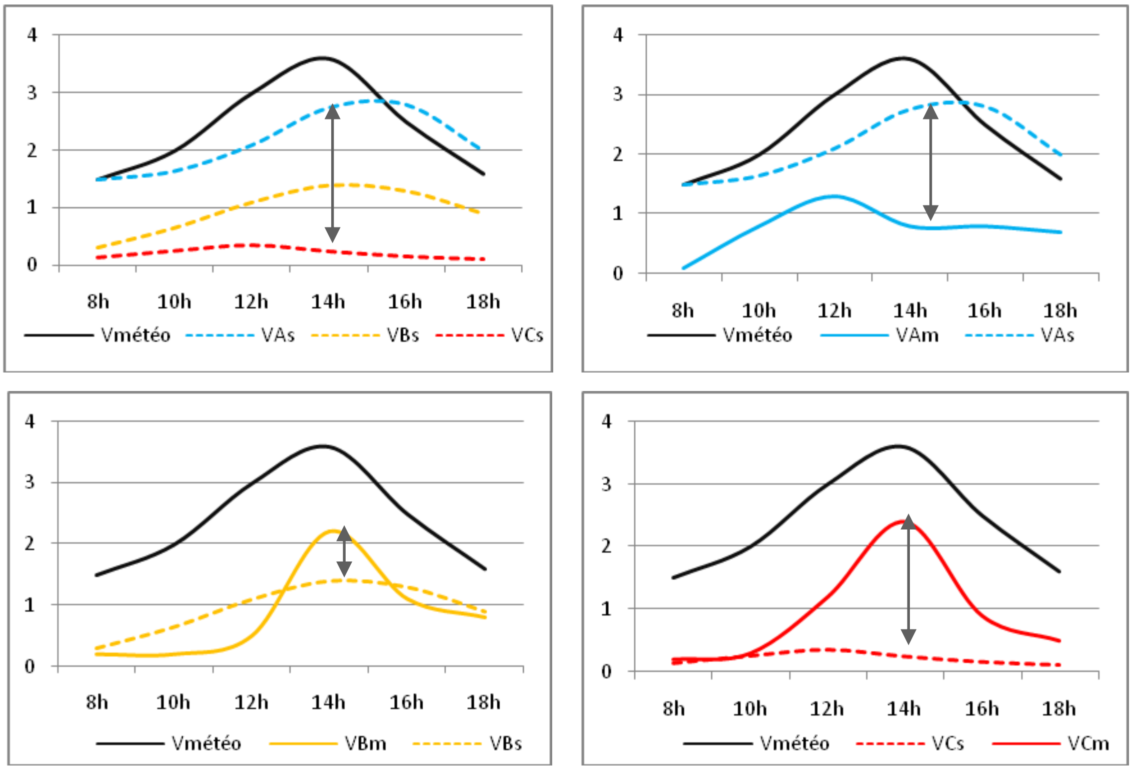


Fig.11. Comparison between simulated and measured wind speeds at points A, B and C (winter)

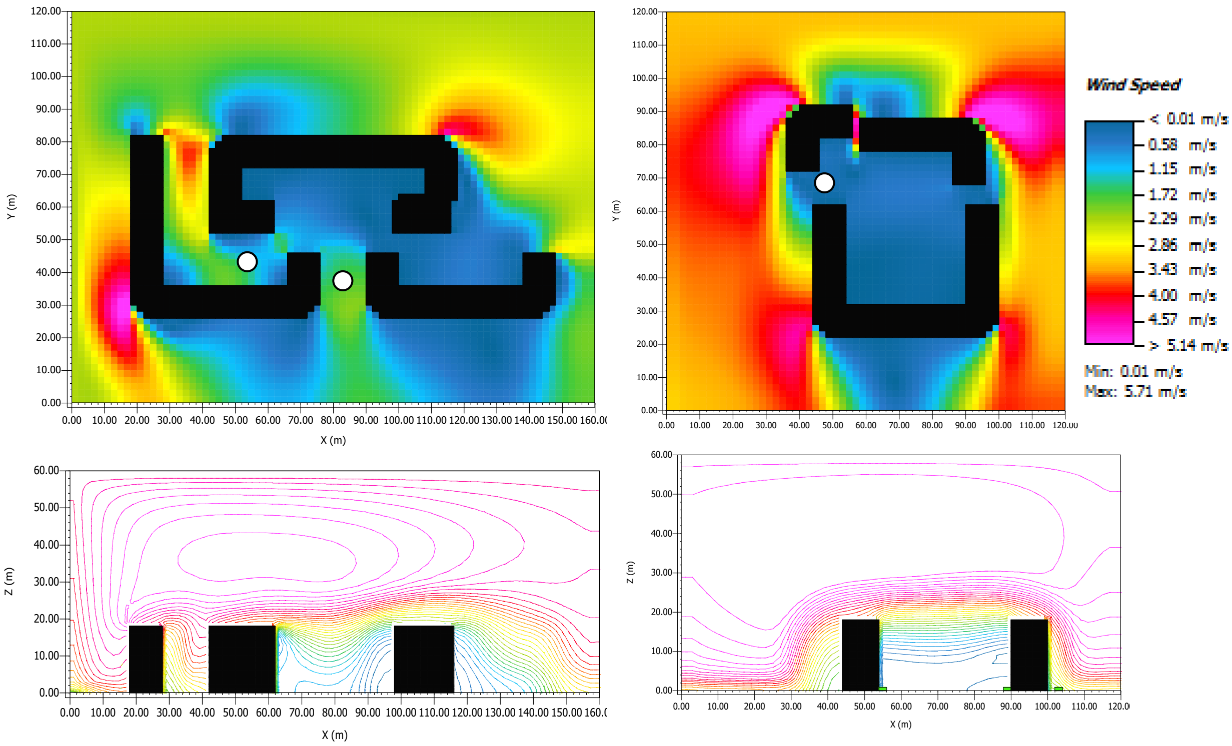


Fig.12. Wind speed in Data results at 14a.m (winter), plans and section

4. 2. In summer

The reading of the simulation results for the summer period shows that point A is distinguished not only by important speeds all day long, but also by its threshold exceeding the speeds of reference, particularly from 11a.m.onwards [Fig. 13]. On the other hand point C happens to have very low speeds and this makes it very badly ventilated [Fig. 14]. In summer, cooling by the wind has always been welcome but that is not straightforward, especially in the case of point A where winds have exceeded the threshold of wind-induced discomforts. This can be explained by the way buildings are arranged, thus creating a canalization facing the wind at A and a closed space which deviates the wind flow.

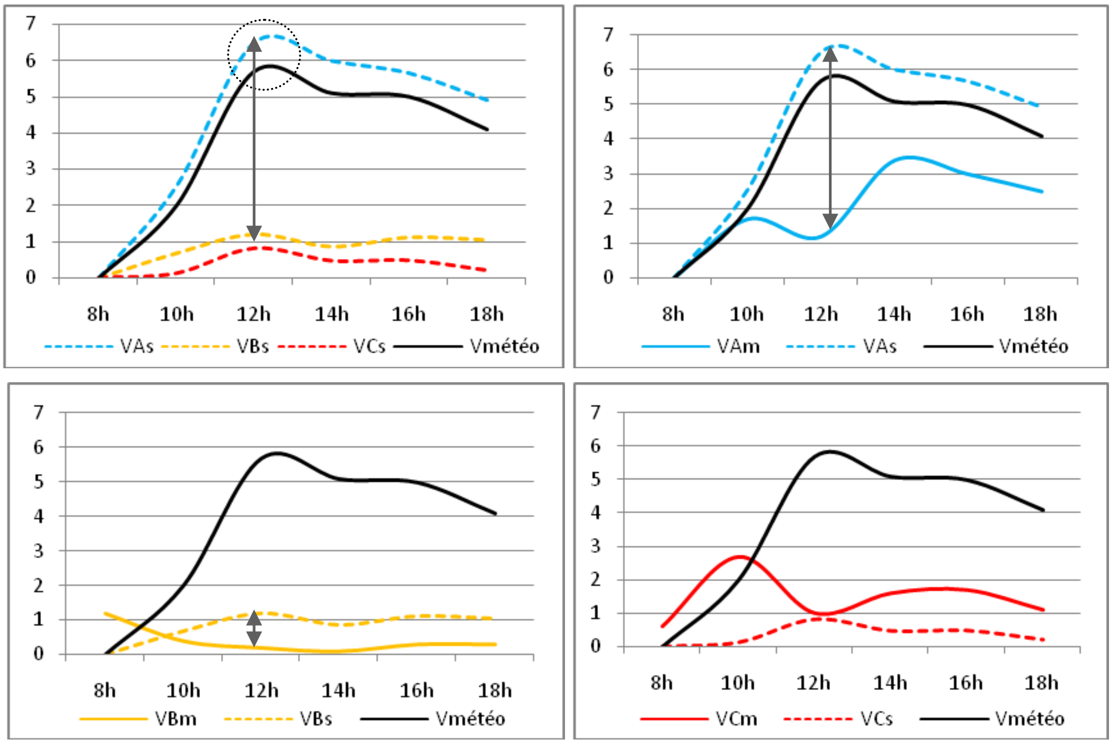


Fig.13. Comparison between simulated and measured wind speeds at points A, B and C (summer)

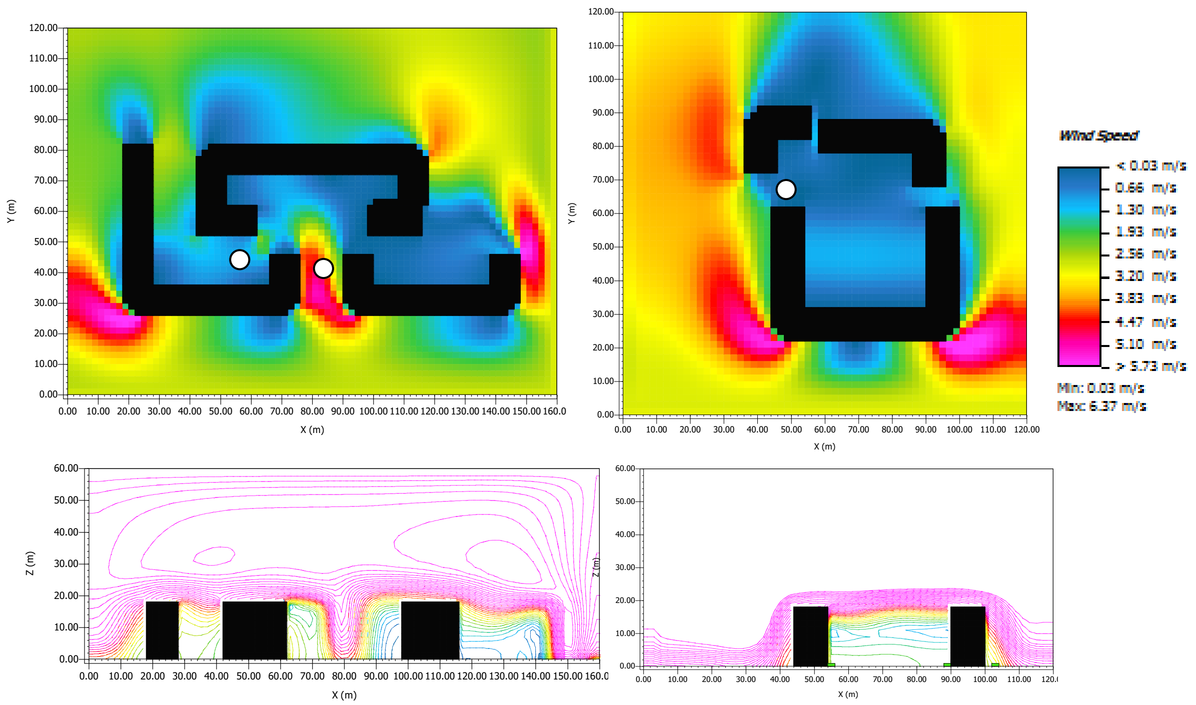


Fig.14. Wind speed in Data results at 14 a.m (summer), plans and section

4. CONCLUSION

The object of this study has been to evaluate the role of urban geometry in controlling the wind in outdoor urban space. This evaluation is based on a method that is structured in two main steps: a microclimatic evolution through in-situ measures, and a numerical simulation with the help of ENVI-met software in order to bring out the behavior of the wind in and around the outdoor space. The simulations conducted with this thermo-hygro-aerolic instrument made it possible to characterize the wind flow around the buildings and the effect of the built-up configurations on its behavior in the case of specific study cases.

The results provided, obtained from numerical simulations, are relatively close to reality. The impact of certain geometric indicators reputed to have a great influence on the wind parameter, more particularly the “prospect” H/w, turned out to be apposite for tempering or raising the exposure, sheltering or even protection level of the outdoor areas. It is then the geometric parameter which has the main impact on urban ventilation. As a matter of fact, the space between buildings has to be calculated in connection with the wind incidence.

Conversely, the geometry of outdoor space, shaped mainly by the arrangement of the surrounding buildings, has a significant impact on wind behavior and takes part in controlling it. This was noticeable with U and L geometric forms which, depending on the free space available, have created badly ventilated enclosed spaces. The wind-related incidence can also play a significant role in amplifying, canalizing or blocking the wind.

5. ACKNOWLEDGEMENTS

I would like to express my sincere gratitude and appreciations to my supervisor, Pr. Y.BOUCHAHM for her great supervision and guidance throughout this research. A special thanks to my family for help during investigation periods, endless supports and advices in completing this research. Last but not least, my deepest thanks to Mr. BENCHOUIEB A.K for providing language help and proof reading the article.

6. REFERENCES

[1] Lévy A. Urban forms and meanings: revisiting the urban morphology. Spaces and societies, 2005, 4(122), 25-48.

[2] Allain R. Urban Morphology: Geography, Planning and Architecture of the City. Armand Colin édition, Paris, 2005.

[3] Givoni B. Man climate and architecture. Elsevier Science Ltd Ed, 1978, 337

[4] Givoni B. Climate considerations in building an Urban Design. John Wiley & Sons INC, New York, 1998, .464

[5] Bottema M. Urban roughness modelling in relation to pollutant dispersion. Atmospheric Environment, 31 (18), 1997, 3059-3075.

[6] Al-Sallal Khaled A., Al-Rais Laila. Outdoor airflow analysis and potential for passive cooling in the modern urban, context of Dubai. Renewable Energy, 2012, 38, 40-49.

[7] Kitous S., Bensalem R., Adolphe L. Airflow patterns within a complex urban topography under hot and dry climate in the Algerian Sahara. Building and Environment, 2012, 56, 162-175

[8] Priyadarsini R., Kee Chuan L., Elmira J. Urban heat island and wind flow characteristics of a tropical city. Solar Energy, 2014, 107, 159-170.

[9] Blocken B., Janssen W.D., Hooff T. van. CFD simulation for pedestrian wind comfort and wind safety in urban areas: General decision framework and case study for the Eindhoven University campus. Environmental Modelling & Software, 2012, 30, 15-34.

[10] Panerai Philippe et al. Analyse urbaine. Editions Parenthèses, Marseille, 1999.

[11] Andreou A. The effect of urban layout, street geometry and orientation on shading conditions in urban canyons in the Mediterranean. Renewable Energy, 2014, 63, 587-596.

[12] Adolphe L. et al. Ilots de fraicheur urbains''IFU''rapport final de recherche, ENSA Toulouse, 2015, 105.

How to cite this article:
Bouketta S, Bouchahm Y. A numerical and experimental study of urban geometry's control of wind movements in outdoor spaces, case of a humid climate. J. Fundam. Appl. Sci., 2019, *11(1), 412-429.*