Research Article

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Local wind in urban canyons of a residential area in Quito-Ecuador

Abstract

This study evaluates the behavior of the wind from its speed in representative urban canyons of residential buildings in the city of Quito. The methodology was based on the selection of case studies from the area of Concepción located in the north of the city to build simplified models according to their aspect ratio height / width (H / W) in blocks of 250 m by 250 m. In each case includes multiple configurations of urban canyons, giving priority to the west-east and north-south orientations, which are simulated by the application of Computational Fluid Dynamics (CFD). The local wind is evaluated according to pedestrian height and their predominant direction obtained from the historical information obtained from the weather station in the area. The results show that the predominant relationship of the wind retains higher speeds when it flows canyons with a lower H/W ratio.

Keywords: wind speed, urban canyons, orientation, computer simulation, Quito

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Introduction

Building design considers variables such as thermal comfort and air. The first variable is widely studied, however that variable is related to air circulation that depends of exterior wind.[1] Understanding wind at a smaller scale is complex because the local landscape typology has an important effect on urban morphology.[2,3] Additionally, the study of wind is fundamental to assess urban design, in dimensions such as air quality, pedestrian comfort and natural ventilation.[4–6]

Buildings as obstruction modifies wind intensity that influences in comfort and ventilation.[7] In some studies, building morphology is analyzed as a study unit called urban canyon. This last element can identify a morphological descriptor known as aspect ratio, which is the facade height divided by the width of the street (H/W).[8] Simultaneously, this descriptor has been used to evaluate urban centers in Latin American cities.[9,4,10,11]

Additionally, the geographical situation with varied topography of the mountainous profile influences the wind in a strong way.[12] This quality becomes important in Andean cities that are strongly conditioned by the presence of the wind flow from the Andes mountain range.[13,14] In some cases, highland cities such as Quito have a north-south valley configuration that prioritizes wind flow in the mentioned direction.[15]

Respect to methodological aspect, some experimental studies require information on climatic variables such as wind from weather stations. This information collected is used to analyze various case studies, but its use may limit by the installation and safety of the equipment used.[16]

A methodological alternative for a case study analysis involves simplified models using Computational Fluid Dynamics (CFD). Among the applications of CFD there are studies from a smaller scale to simulate the wind tunnel in greenhouses, up to larger scale cases in simulations of urban space through urban canyons.[17,1,18]

For the above, the study of the morphology is fundamental to characterize the study of the local wind. The study of climate related to morphological situations in the Andean city of Quito has been limited. Inside this territory, a useful scale of study is housing residential, which in practice is influenced by urban design at the pedestrian level. Thus, this study determines the effects of wind on urban canyons through the comparison of different morphological compositions in relation to the prevailing wind speed.

Material and methods

Study area delimitation

The Metropolitan District of Quito is the most important conglomerate of the Republic of Ecuador. It is located at coordinates 0° (latitude) and 78°S (longitude) of the Ecuadorian highlands, with an average altitude of 2,900m asl (Figure 1). According to the Koppen-Geiger climate classification, the city of Quito is classified as Cfb, which corresponds to a mid-latitude, humid and temperate climate.[19]

The study area is delimited as the north-central sector of the city belonging to the Eugenio Espejo zonal administration, focusing on the urban parish of Concepción (Figure 1). This sector was chosen because of the following characteristics:

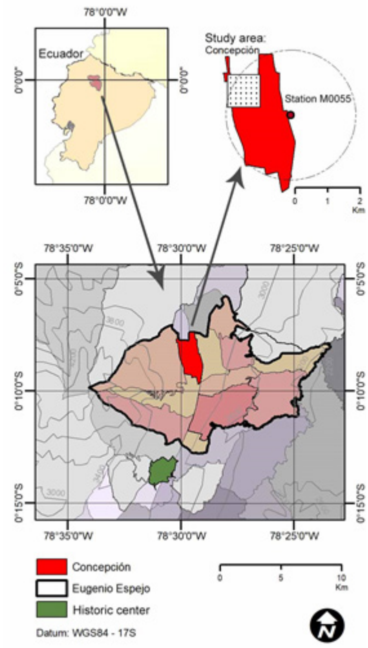

Figure 1 The Geographical location of Quito and focus on Concepción. Own elaboration.

1) The zone includes an area for residential use with a varied morphology.
2) The importance of the local wind suggests the study of this area because it is within the closest area of influence of the meteorological data station (M0055).[20] It has a complete historical record and shows the highest wind intensities for this area of the city of Quito.[21]
3) Finally, this zone maintains a similar altitude that avoids variations in wind intensity.

Mapping and case studies

The study used a preliminary area of 1km^2 (Figure 2). Thus, the evaluated location of Concepción will be defined as a representative block and by its disposition in the urban layout. The methodology for these purposes was based, first, on a mapping of the study area using tools such as Google Maps and Google Street View, and second, information from the municipal land base to define a geometry according to horizontal and vertical measurements.[22] The next step consisted of defining case studies using four 250m by 250m quadrants (Figure 2), which include various configurations of the H/W aspect ratio (division of building height to street width). Each quadrant considers at least 5H/W values for both west-east (WE) and north-south (NS) orientations. Simultaneously, this selection corresponds to the internal quadrants, which previously contemplate the obstruction of the immediate external morphology.

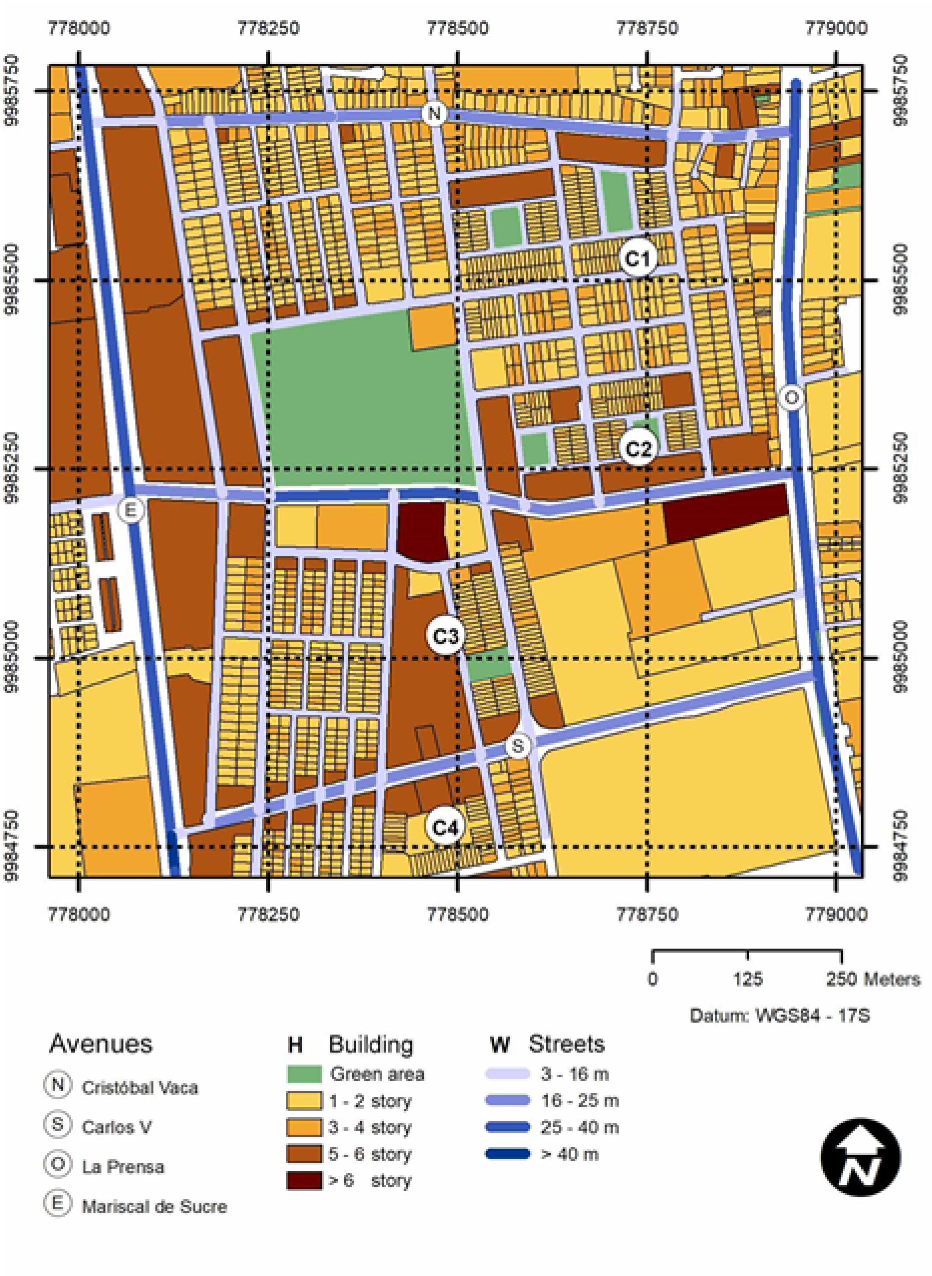

Figure 2 Mapping of the geometries and study quadrants. Own elaboration.

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Wind characterization in the study area.

The predominant wind characteristics over a 30-year period (1980-2012) are shown in (Table 1).[21] The study used information from the meteorological station at the former Airport Mariscal Sucre -today Bicentenary Park- located at coordinates 0° 8′ 28″ -South-, 78° 29′ 19″ -West-, which takes wind records at a height above 10 m from the surface. The average speed was 11.09km/h (3.08m/s). Simultaneously, extreme wind speed dates were identified. August shows the highest speed of 12.9km/h (3.58m/s), while April shows 9.7km/h (2.69m/s), which according to the Beaufort wind scale is classified from light to gentle breeze.[23] On the other hand, the highest frequency of winds comes from the north, specifically from the north-northwest (NNW) direction.

Table 1 Historical climate data for Quito 1980-2012 (station M0055).[21]

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AGU	SEP	OCT	NOV	DIC	AVE
Temperature (°C)	13,6	13,6	13,6	13,5	13,8	13,6	13,7	13,8	13,7	13,5	13,3	13,5	13,6
Precipitation (mm)	81,2	102	136	151,6	94,2	37,7	19,4	19,8	59,5	98,2	94,7	82,3	81,4
Wind velocity (km/h)	11,2	11,4	10,4	9,7	10,0	10,5	11,8	12,9	11,9	10,8	11,0	11,5	11,1
Prevailing direction (higher frequency)	NNW	NNW	NNW	NNW	NNW	NNW	NNW	N/ NNW	NNW	NNW	NNW	NNW	NNW

In additionally, based on data from the same station, wind roses previously elaborated with information generated by the Energy Plus database (Figure 3). The weather information is based on the former airport station -840710-[24]

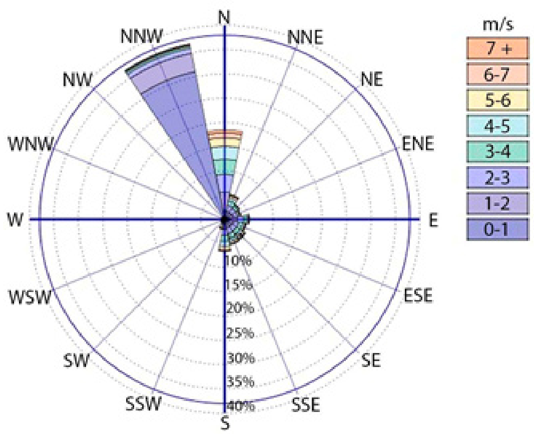

Figure 3 Wind direction and intensity at station-840710.[24]

Calculation of wind intensity at an urban canyon scale.

Wind was assessed at an urban canyon scale of 1.5 m, similar to the study by Rajagopalan, Lim, and Jamei.[7] To calculate the wind speed at pedestrian level, the logarithmic wind profiles formula was used (1)[25]:

$$v = v_{ref}\left[\frac{In\left(z/z_o\right)}{In\left(z_{ref}/z_o\right)}\right] \qquad (1)$$

Where v is the wind speed at a height z above the ground level, v_{ref} is the reference speed (known speed at a height), In is the natural logarithm function, z is the height above the ground level for the desired speed, z_o is the roughness length in the current wind direction, and z_{ref} is the reference height (height at which the wind speed is known).

With expression 1, we calculate the velocity for the urban canyon profile, from the average velocity of 3.08m/s, for a velocity height at 1.5m, a roughness length of 0.8.[26]

Replacing in 1:

$$v = 3,08\left[\frac{In\left(1,5/0.8\right)}{In\left(10/0.8\right)}\right]$$

$v =$ 0,77m/s

Modeling, simulations, and graphics processing

Subsequently, the three-dimensional models with their geometry were generated, and the wind is evaluated trough spaces between the streets and the buildings. The wind tunnel effect was then simulated graphically using the Autodesk Vasari Beta software.[1]

Additionally, the resulting plots at the points of interest were evaluated using QGIS 2.4 software, which determined the value of each pixel, and at the same time allowed to obtain the simulated wind speed value at a point of interest. This linearity relation is expressed in equation 2.

$$v = \frac{Vpix * Vel_{máx}}{Vpix_{máx}} \qquad (2)$$

Where v is the wind speed at the searched pixel, $Vpix$ is the pixel value at the analyzed point, $Vel_{máx}$ is the maximum speed recorded in the simulation and $Vpix_{máx}$ is the maximum pixel value for the maximum speed (255). Grayscale images contain the same value for the red, green and blue scales (RGB). Finally, these velocity values are correlated with the H/W values for each point obtained from the initial mapping based on the sectors of interest in the urban canyons evaluated.

Results

The results are explained based on the profile of 1.5m simulations for the evaluated quadrants.

The results at a 1.5m profile (Figures 4–7) showed that in most of the cases analyzed, there is a tendency of the wind retains higher speeds when it flows canyons with a lower H/W ratio. In other words, although the simulation speed decreases when entering urban canyons, morphologies with a lower H/W value allow a better passage of the wind that is not limited in speed.

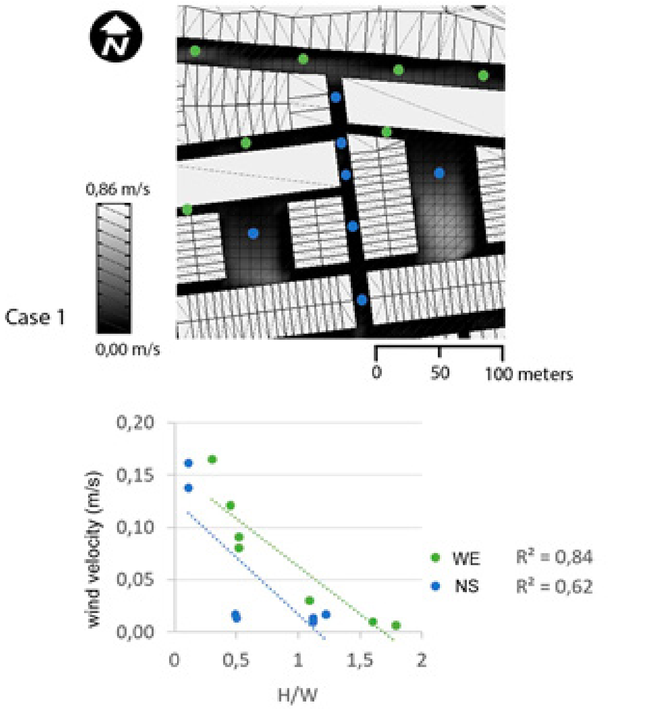

Figure 4 Case 1 and simulation of wind speed at 1.5 m from the ground, and the correlation between H/W and wind speed. Own elaboration.

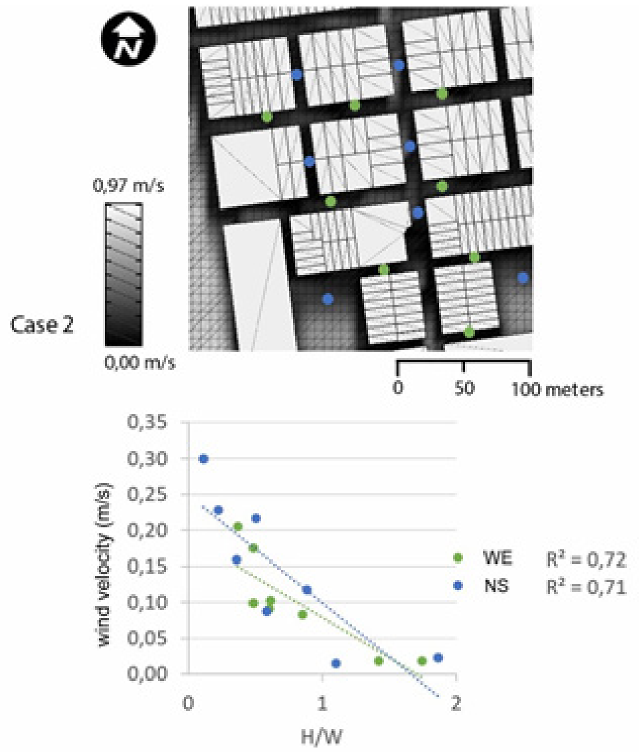

Figure 5 Case 2 and simulation of wind speed at 1.5 m from the ground, and the correlation between H/W and wind speed. Own elaboration.

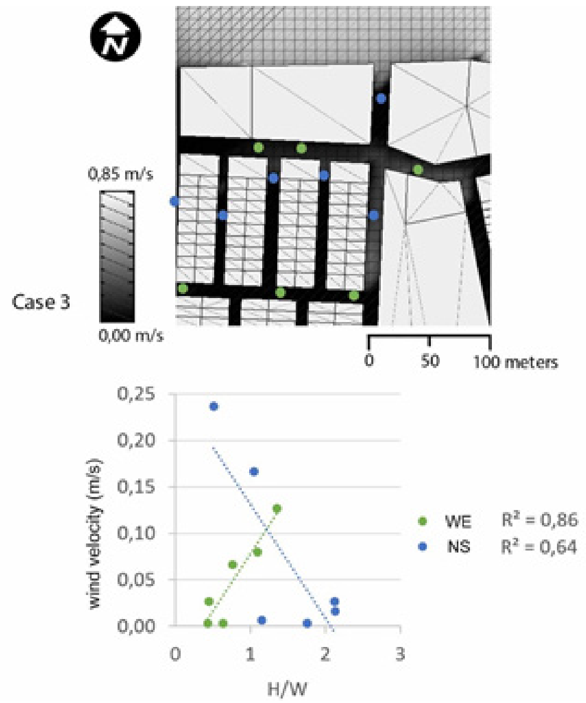

Figure 6 Case 3 and simulation of wind speed at 1.5 m from the ground, and the correlation between H/W and wind speed. Own elaboration.

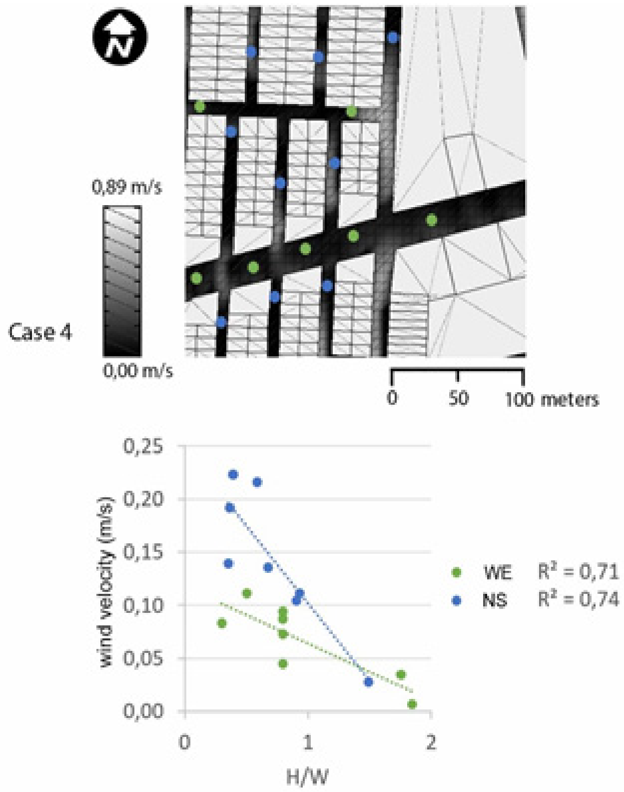

Figure 7 Case 4 and simulation of wind speed at 1.5 m from the ground, and the correlation between H/W and wind speed. Own elaboration.

On the other hand, this analysis is better classified if this is described the relationship by orientation. Thus, it is observed that the four cases analyzed for the NS orientation showed an R^2 greater than 0.62 (Figures 4–7) while the WE orientations showed a similar trend with R^2 values greater than 0.71. However, in case 3 for WE orientations, the relationship was defined that the wind retains higher intensity speeds when it flows canyons with a higher H/W ratio (Figure 6). This is explained below.

Discussion

All simulated cases considered the immediate obstructions around the 250m by 250m quadrant. In case 3 (Figure 6), in the northern part there is a green area, which for simulation and modeling was considered a free and open space. Then, this effect modifies in the morphology, from which the prevailing wind advances in the NNW direction without obstruction, and the wind flow penetrates directly into the canyons, following the WE orientation that is slightly inclined to the south. In any case, this is the only case with a different relationship, so this last trend cannot be generalized.

From the previous paragraph, a specific characteristic of the morphology emerges, which are the openings or green areas. These register higher wind speeds, considering their lower H/W (0.3) as spaces that do not present tall buildings as obstructions and can be ventilated from the oncoming (north) wind.

The geometry studied used the (virtual) wind tunnel tool to evaluate the effect of wind around solids, which in this case are streets and buildings. Thus, the wind study for the 1.5m analysis profile, being at a lower level than the obstructions (buildings), allows the free flow of wind in the urban canyons, with a velocity range between 0 until 0.30 m/s. Additionally, regardless of the orientation, all cases show an R^2 value of 0.4, with the predominant relationship of the wind retains higher speeds when it flows canyons with a lower H/W ratio (Figure 8).

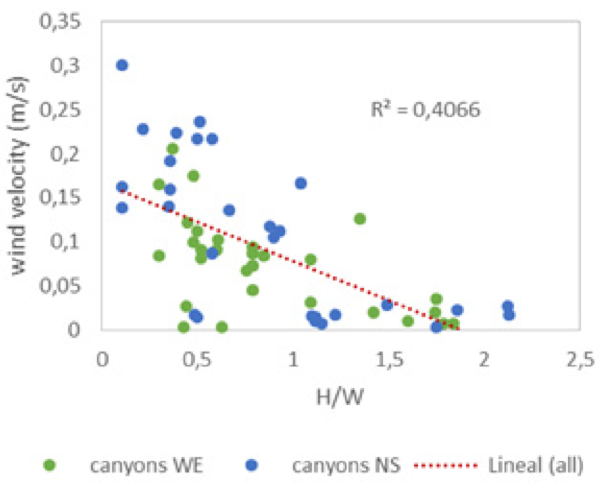

Figure 8 Ratio of wind speed and H/W at 1.5m for all case studies. Own elaboration.

Regarding the wind simulation study of Rajagopalan, Lim and Jamei[7] conducted in a tropical city indicate that wind intensities at 1.5m profile has velocity values from 0.01m/s.[7] This value is similar to the results obtained for this study. On the other hand, wind speeds recorded in an experimental study for a few numbers of urban canyons with H/W values between 0.2 and 2 in Cuenca, with climatic characteristics similar to Quito, showed wind speeds inside the canyon of up to 1m/s at a height of 3m.[10]

Bustamante[9] shows results of different directions and wind speeds in different periods and indicates that there is a higher wind intensity when the wind flows urban canyons with a higher H/W ratio; however, this study shows values that the lower the H/W ratio value, the wind gets faster speed.[9] These results differ from Cuenca and Quito, although they have a similar climate, these may differ because the prevailing wind analyzed comes from different directions. Moreover, case studies in Quito have different morphologies and the height of the buildings are greater and the simulation context is wider. In any case, both results highlight the role of morphology in modifying the wind intensity.

Bustamante[9] in the historic center of Quito analyzed the relationship between wind and morphology by day and afternoon periods and highlights the importance of thermal modification and the capacity to ventilate.[4] In that study, the results show that the wind retains higher speeds when it flows canyons with a lower H/W ratio. This behavior was similar to this study.

The scale of analysis at 1.5m or pedestrian scale suggests an important height to reflect ventilation and comfort at the urban level, since these two variables depend on wind intensity. Additionally, it is observed that the relationship between morphology and wind, depends on other things such as layout, orientation and urban canyons dimensions.

Conclusion

This investigation analyzed the effect of the prevailing wind from the NNW direction at a height of 1.5m in the WE and NS orientations. The results show that the predominant relationship of the wind retains higher speeds when it flows canyons with a lower H/W ratio. Thus, the geometric configuration of the urban canyon modifies the wind intensity inside of it. The methodological procedure used is adaptive to the cases studied, so that different urban canyons could be analyzed starting from a known wind speed. This is achieved using CFD as an advantage that basically requires data such as prevailing historical wind intensity and direction. Additionally, this information was taken from the closest station with a similar altitude range for the area studied.

On the other hand, the delimitation of the study area at a similar altitude is useful for the study. So that only the morphology was evaluated and avoids modifications due to differences in altitude.

It is concluded that the study of the urban canyons, through the use of the H/W ratio, is an analysis capable of simplifying urban climate behavior to conduct sustainability research.

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Conflicts of interest

The author declared that there is no conflict of interest.

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