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THE INFLUENCE OF SURROUNDINGS OBSTRUCTION ON THE AIRFLOW OF A RESIDENTIAL BUILDING

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RESUMO

A ventilação natural é uma estratégia passiva de resfriamento recomendada para grande parte do Brasil, porém, é um fenômeno complexo influenciado por muitos fatores. Estudos prévios indicaram a relevância da obstrução do entorno e do ângulo de incidência do vento para a ventilação dos edifícios, e demonstraram que pequenas mudanças podem diminuir ou aumentar a vazão significativamente. Além disso, existem poucos estudos avaliando a ventilação em edifícios em formato de duplo “H”, apesar de ser um formato comum em edifícios multifamiliares no Brasil. Neste sentido, este trabalho investigou o efeito da obstrução do entorno com vários ângulos de incidência do vento no fluxo de ar. O objeto do estudo foi um prédio residencial no formato de duplo “H localizado em Piracicaba, SP. O estudo foi realizado através da simulação CFD (*Computational Fluid Dynamics*). Foram realizadas seis simulações com diferentes ângulos de incidência do vento e obstruções do entorno (três modelos obstruídos e três desobstruídos). Ao final foram produzidas imagens com vetores de velocidade e uma tabela com a média das velocidades do ar resumindo os resultados. Estes indicam que a altura do pavimento influencia a velocidade de entrada do ar nos apartamentos apenas nos prédios com entorno desobstruído. Também se observou que as obstruções do entorno têm maior influência no fluxo de ar do pavimento térreo. Além disso, recomenda-se atenção com relação a posição da janela do banheiro evitando que ela funcione como entrada de ar para outros ambientes. Por fim, o formato em “duplo H”, não provê boa ventilação em todos os apartamentos simultaneamente, portanto tal formato não é recomendado para uma boa ventilação. Assim, o trabalho dá suporte ao projeto de sistemas de ventilação natural, contribuindo para a diminuição dos gastos energéticos com condicionamento artificial dos ambientes.

Palavras-chave: ventilação natural, CFD, obstrução do entrono, ângulo de incidência do vento.

ABSTRACT

Natural ventilation is a passive cooling strategy recommended for most of Brazil, however, it is a complex phenomenon influenced by many factors. Previous studies indicate the relevance of surroundings obstruction and incidence angle, showing that small changes can significantly decrease or increase the airflow rate. In addition, there are few studies evaluating ventilation in buildings configured as a "double H", although this is a common architectural typology in residential buildings in Brazil. Accordingly, this paper aims to evaluate the effect of surroundings obstruction at different wind attack angle on the airflow. The object of this study is a residential building configured as a "double H" located in Piracicaba, São Paulo State (Brazil). The study was carried out using simulations in CFD (Computational Fluid Dynamics). Six simulations with different wind attack angles and surrounding obstructions (three obstructed and three unobstructed models) were carried out. For analysis there are presented images of velocity vectors and a table of the average wind speed summarizing the results. The results show that the floor level influences the air velocity. It was also observed that the surroundings obstructions have greater influence airflow on the ground floor. In addition, the bathroom window should be designed in such a way to prevent it from working as an air inlet for other rooms. Finally, the shape of the studied building does not provide good ventilation in all apartments. Thus, the work gives subsidy for the design of new buildings with proper ventilation, thus contributing to decreasing energy expenses with artificial air-conditioning.

Keywords: natural ventilation, CFD, surroundings obstruction, wind incidence angle.

1 INTRODUCTION

Wind driven ventilation is the most used passive strategy to remove the excess of heat load of building in tropical climates (AFLAKI *et al.*, 2015). It is a valuable approach to achieve thermal comfort at low cost (MORAIS; LABAKI, 2013) and therefore can contribute to energy savings (PEREIRA *et al.*, 2013).

Nevertheless, wind driven ventilation is a complex phenomenon and airflow inside buildings can be influenced by many factors, such as the surroundings obstruction. The accelerated growth of urban areas in the recent years drew attention to the influence of urban density on urban airflow (BUCCOLIERI, 2011; NG *et al.*, 2011; YUAN; NG, 2012), and recommendations have been outlined to access designers to improve wind performance in buildings (ALLARD; GHIAUS, 2012; KUANG; CHEN; SUN, 2015; MIRZAEI; HAGHIGHAT, 2012).

Researches demonstrate that the surroundings obstruction can change the direction and intensity of the winds, directly affecting the ventilation flow inside the buildings (OLIVEIRA, 2009). For example, a change of 5º in the incidence of wind can change the flow of 5% to 40% (CÓSTOLA, 2006).

Another key feature is the wind attack angle towards the building windows (ALI; MILAD; ALI, 2007; LUKIANTCHUKI; CARAM, 2012) which can represent up to 20% increase in ventilation inside building (CÓSTOLA, 2006). A research on social housing investigated three common architectural typologies in Brazil and showed that most of these building, including the H-shaped one, present ineffective wind ventilation systems. The authors indicated that few low-cost modifications would suffice to improve this situation, for example: the correct orientation towards prevailing winds, the positioning of the windows, and also the adoption of asymmetric building form (MORAIS; LABAKI, 2013).

Although there are investigations about the influence of the surrounding obstruction to airflow, some common architectural typologies have not yet been investigated, such as the "double H" (two buildings shaped like an "H" positioned together). In this regard, this paper aims to evaluate the effect of surroundings obstruction, floor level, and wind attack angle on the airflow of a residential building configured as a "double H".

2 METHOD

The reference for this work is a residential building located in Piracicaba, São Paulo State (Brazil). This study considered two surrounding obstruction situations (obstructed and unobstructed) and 3 wind attack angles (0°, 45°, and 90° clockwise - Figure 1) resulting in 6 models. The data for this research were obtained through simulations in CFD (Computational Fluid Dynamics), by using the software CFX.

The city climate is described as humid subtropical - Köppen classification system (CEPAGRI, 2016). The average humidity is higher than 70% through all year; the maximum average temperature in summer is 28,50°C and in winter 26,19°C, the average minimum in summer is 18,96°C and in winter 12,48°C (RORIZ, 2012a), which shows that even in winter high temperatures are observed, therefore ventilation is needed throughout the year. In addition, for Piracicaba, the wind prevailing direction is from 65° to 155°. Although this study is not focused on evaluating the ventilation of the reference building, it is possible to relate the results to the predominant directions that occur in the reference situation.

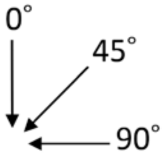


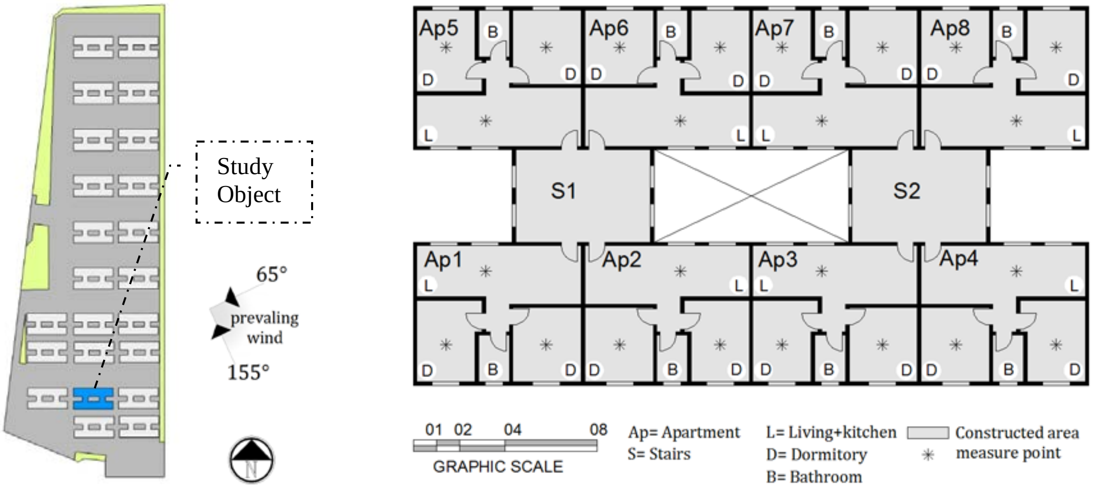
Figure 1. Simulated wind angle attack

2.1 Model

For the selection of the reference building, the following conditions were considered: to be part of a social housing program, to have an usual floor plan for the considered city, and to display uniform floor plan. Therefore Parque Piazza Navona residential complex was chosen because it not only meets these criteria but was the most populated. It is composed of 23 apartment blocks (as seen in figure 2-a). The location of the building at the residential complex (highlighted in figure 2-a) was selected for being the most obstructed one. It was adopted as a reference for the simulation of the obstructed surroundings, while for the unobstructed models it was used the same building but without the surrounding.

The reference building is a four-story building and only the first and fourth floor were analysed on the results. It is configured as a "double H" (two buildings shaped like an "H" positioned together) and it forms a central courtyard limited by the stairs towers. It also presents two side recesses (Figure 2-b). The apartments are composed of two bedrooms (nocturnal area), a kitchen integrated to living room (diurnal area), and a bathroom (figure 3-a). It is worth of mention that the measuring points presented in figure 2-b are used to formulate table 3.

All windows of the building were considered as having the same size (J1), except the bathroom window that is smaller (J2), as described in table 1. The bedrooms and bathrooms have only one window, the integrated living room has two windows, as well as the corridor, see figure 3.



(a) **(b)**

Figure 2. (a) - Location of the reference building at the residential complex; (b) - Floor plan of the Parque Piazza Navona residential complex.

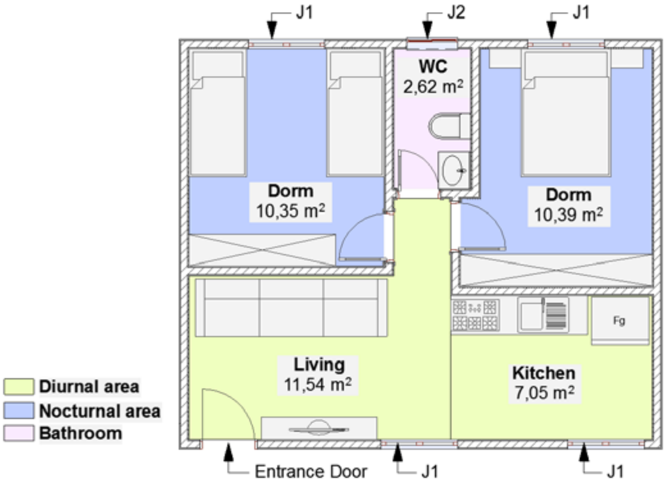


Figure 3. Floor plan of one apartment of Parque Piazza Navona.

Table 1. Description of the simulated windows and ventilation areas.

WINDOW NAME	WINDOW TYPE	N° OF SLIDING PANELS	ACTUAL HEIGHT [m]	ACTUAL WIDTH [m]	TOTAL AREA [m2]	VENTILATON HEIGHT [m]	VENTILATION WIDTH [m]	VENTILATION AREA [m2]
J1	Sliding	2	1.00	1.20	1.20	1.00	0.60	0.60
J2	Swings open	-	0.75	0.80	0.60	0.75	0.80	0.60

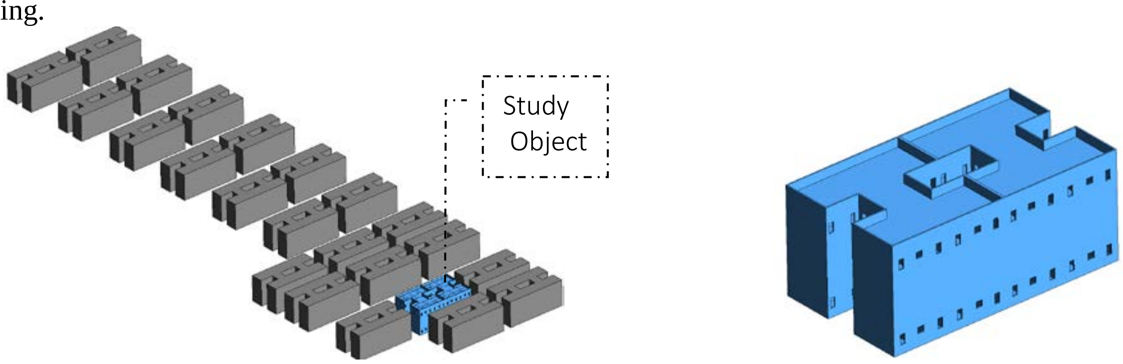
2.2 Computer simulation

The study was carried out in the CFD program CFX 16.2 since it has been successfully applied in similar researches (CÓSTOLA; ALUCCI, 2007; LUKIANTCHUKI; CARAM, 2012; MORAIS; LABAKI, 2013).

Two sets of models (obstructed and unobstructed) were simulated for three wind incidences (0°, 45°, and 90°).

To enable the simulation of various wind attack angles it was adopted an octagonal domain with a 674,43m diameter (50 times the object height) and 77,40m height (5 times the object height), according to recommendations (CÓSTOLA; ALUCCI, 2007). This configuration resulted in a blockage of 0.009%.

In order to represent the obstructed surroundings all buildings of the residential complex were modelled (Figure 4-a), but for the unobstructed surroundings only the analysed building was modelled (Figure 4-b). In addition, all internal partitions of the first and last floor were modelled for the evaluated building.



(a) (b)

Figure 4. Model of the buildings in CFX Ansys 16.2 with obstructed (a) and (b) unobstructed surrounding.

The average annual wind speed of Piracicaba at 10m is 2,46m/s (RORIZ, 2012) so this value was used as the reference wind speed entry for the simulations. In order to consider the boundary layer effect a CCL (Common Command Language) expression was inserted on CFX, the profile was considered neutral, according to (CÓSTOLA; ALUCCI, 2007). After applying this correction, the resulted average inlet speed was 1,06m/s and 2,27m/s, for the first and fourth floor window level respectively.

Mesh independence tests were performed to ensure the accuracy of the model and to define the mesh. Several simulations were carried out by refining the mesh each time. This process continued until a finer mesh did not present significant changes in results, as proceeded in other researches in the field (CÓSTOLA; ALUCCI, 2007; LUKIANTCHUKI; CARAM, 2012; MORAIS; LABAKI, 2013). Thus, the mesh and the model's domain were configured as shown in table 2:

Table 2. Adopted configuration for CFX simulation.

GLOBAL PARAMETERS		DOMAIN INPUT
SIZING		DOMAIN CONFIGURATION
numbers of cells across gap=	3	analysis type= stationary
face size=	2	heat transfer= isothermal at 20ºC
maximum size=	4	turbulence model= k epsilon
growth rate=	1,2	BOUNDARY CONDITIONS
		domain side walls= subsonic opening
		domain top= free slip wall
		domain ground and room walls= no slip wall
MESH CONTROL		ROUGHNESS = smooth wall
Face sizing		CONVERGENCE CRITERIA
Local =	building	maximum residual = 10-4
element size=	0.8m	minimum iterations = 1
growth rate=	1,2	maximum iterations = 600

3 RESULTS AND DISCUSSION

In this section, the airflow inside the apartments of the models at three wind attack angles (0°, 45°, and 90°) are presented. Initially the models are analysed with the obstructed and then with the unobstructed surrounding. The images of the airflow (figures from 3 to 14) show a close-up view of the studied building that allows the qualitative analysis of its interior. In some images the wind attack angle is not clear in the close-up image due to turbulence, therefore it is indicated in the legend. For summarizing the results, table 3 presents the average wind speed of the apartments for different wind attack angles and surrounding obstructions, which enables the quantitative analysis of the results.

3.1 Wind speed vectors

In unobstructed models, the floor height does not influence the airflow inside the apartments, therefore only images of the first floor are presented. However, in the obstructed models, the airflow presented different behaviours at different floor heights; thus, images of the first and fourth floor are presented.

3.1.1 Unobstructed surrounding

By analysing the unobstructed model with wind attack of 0° (Figure 5), it is clear that the ventilation around the building is turbulent. In addition, the windward apartments (Ap 01-04) are well ventilated in terms of velocity but have poor air quality: in these apartments, the living room incoming air flows through the bathroom, which can cause bad odours and increased humidity. While at the apartments 06 and 07 (located in the courtyard) the incoming air flows through neighbour’s apartments (02 and 03), which can also cause bad odours. This is not a constant situation because the ventilation of the leeward apartments only happens if all windows of the windward apartments are open. In this model, all leeward apartments (Ap05-08) have low wind speed, and ventilation occurs mostly due to turbulence.

Figure 7 shows that the apartments 02, 03, 04 and 05 are well ventilated, but in the first three rooms the airflow in the living room comes from the bathroom, which presents the same problems discussed previously. Then in the apartments 06 and 07 the incoming air flows across the apartments 02, 03 and the stairs towers. In this floor, the apartments 01 – 04 behave in a manner similar to those with wind attack angle of 0°, except for the apartment 05 that shows higher velocities and presents acceptable performance.

Observing the wind attack angle of 90° (figure 9 and figure 10) the exterior ventilation is turbulent and only apartments 01 and 05 show good ventilation.

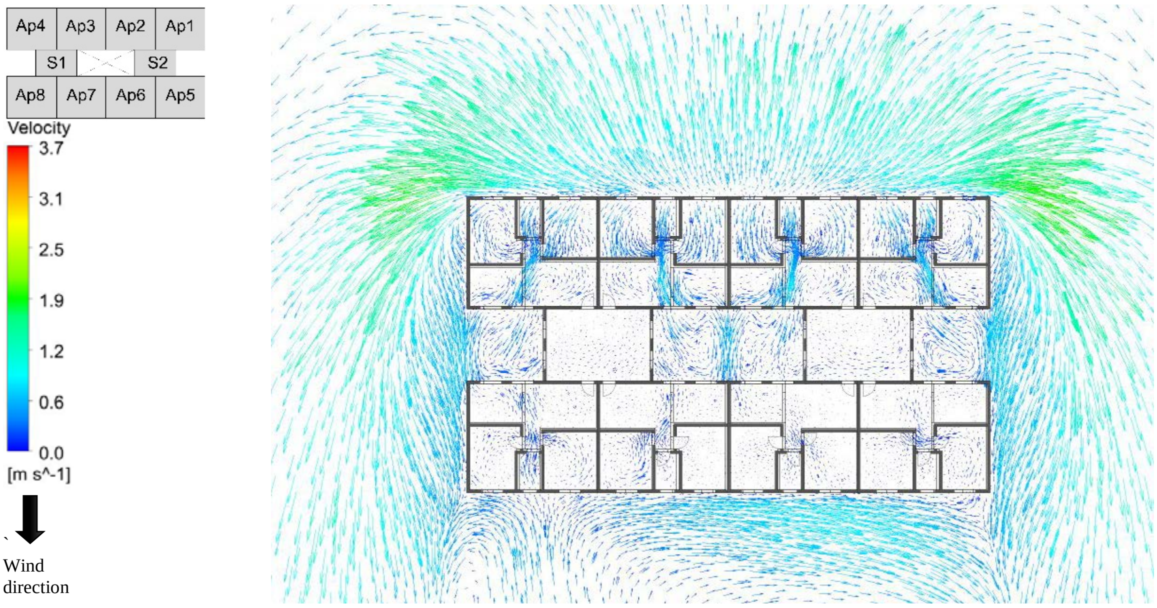


Figure 5. Airflow in the first floor apartments at wind attack angle of 0°, unobstructed surrounding.

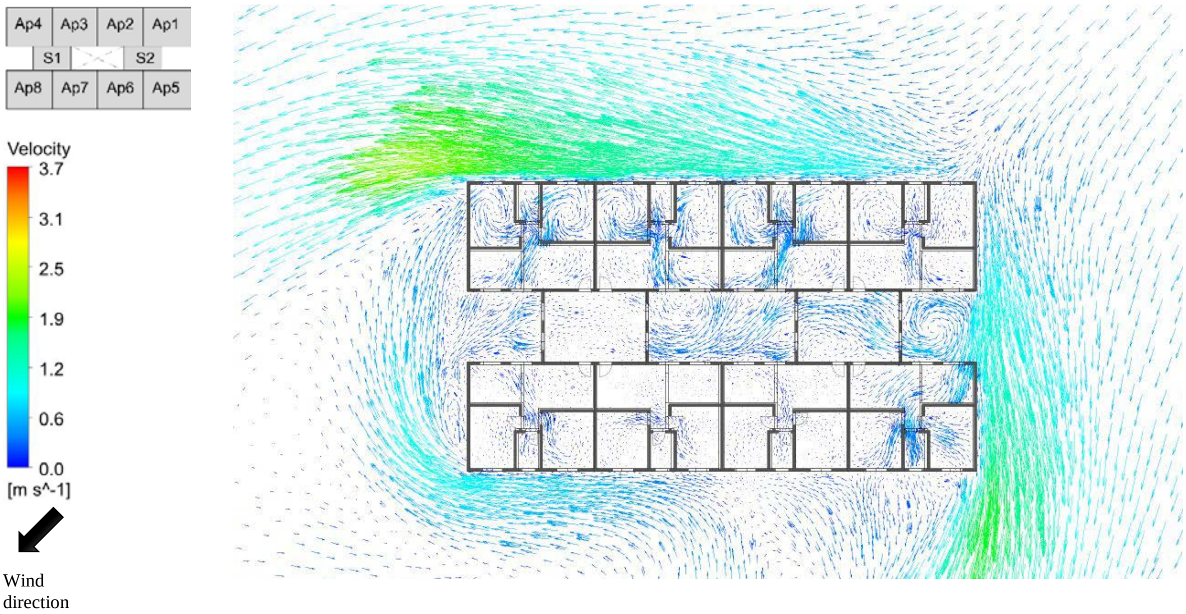


Figure 6. Airflow in the first floor apartments at wind attack angle of 45°, unobstructed surrounding.

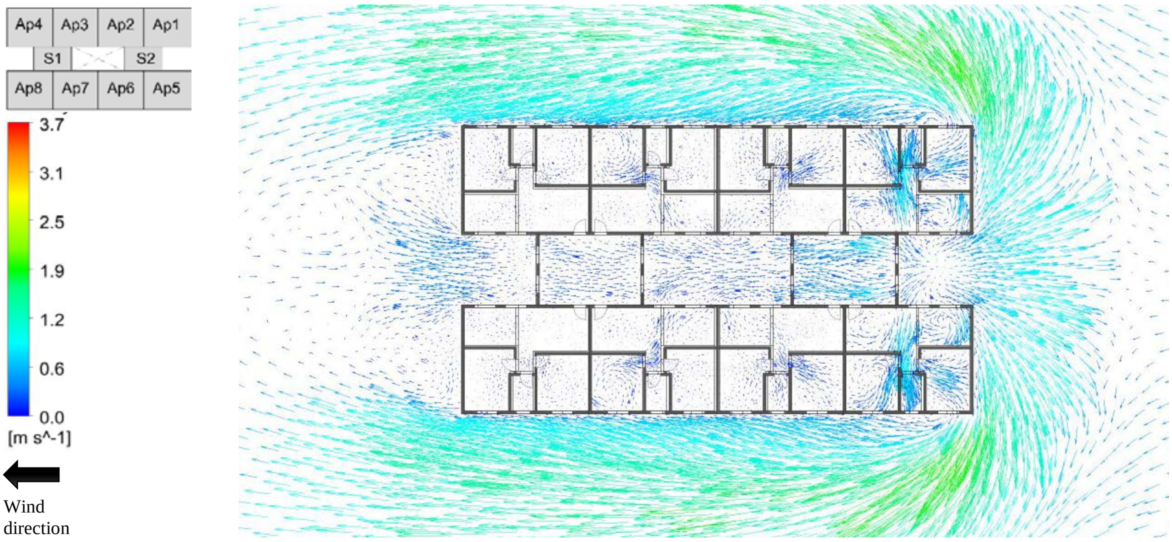


Figure 7. Airflow in the first floor apartments at wind attack angle of 90°, unobstructed surrounding.

3.1.2 Obstructed surrounding

Figure 11 shows the first floor of the obstructed model with wind attack of 0°. In this situation, the wind around the building changes direction due to the obstructions. The wind is tangent to the apartments 01 to 04 and for this reason the ventilation is due to suction with adequate speed, but turbulent. Moreover, the air quality is compromised because it flows through the bathroom before arriving at the living room. Apartments 05 to 08 have similar behaviour to the unobstructed ones at the same wind attack angle, presenting low air speed. At the fourth floor (Figure 12), the wind surrounding the building has higher speed, but the airflow behaviour in the apartments is very similar to that of the first floor.

The model with wind attack angle of 45° (figure 13 and figure 14) show a small difference between the first and the fourth floor. The ventilation is not turbulent and the wind direction does not change considerably. The apartments have low air speed, the first floor presenting the higher values.

Figure 15 presents the results of first floor level at a wind angle of 90°: the wind direction undergoes the influence of the obstruction and the flow is similar to that with 45° wind incidence, but with lower velocities. Then at the fourth floor level (figure 16), the wind direction is not influenced by the obstructions and speed is higher. However, the apartment on both levels shows the same airflow behaviour. Since the first floor level has low incoming airspeed and at the fourth floor the flow is tangent to the windows, all rooms present poor ventilation.

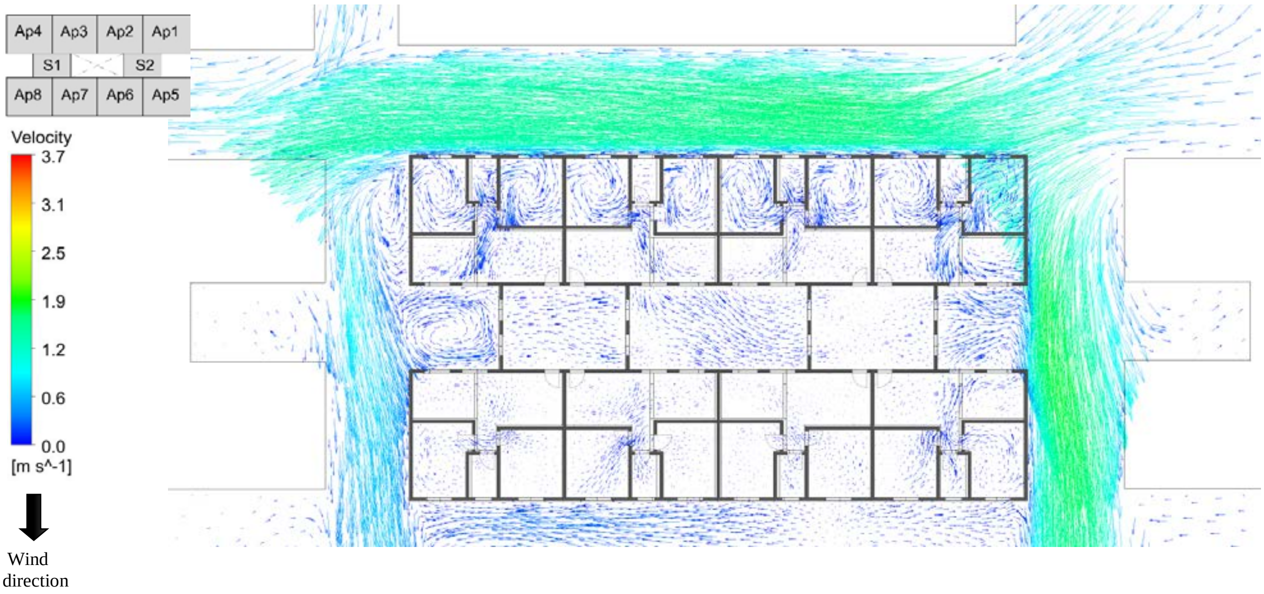


Figure 8. Airflow in the first floor apartments at wind attack angle of 0°, obstructed surrounding.

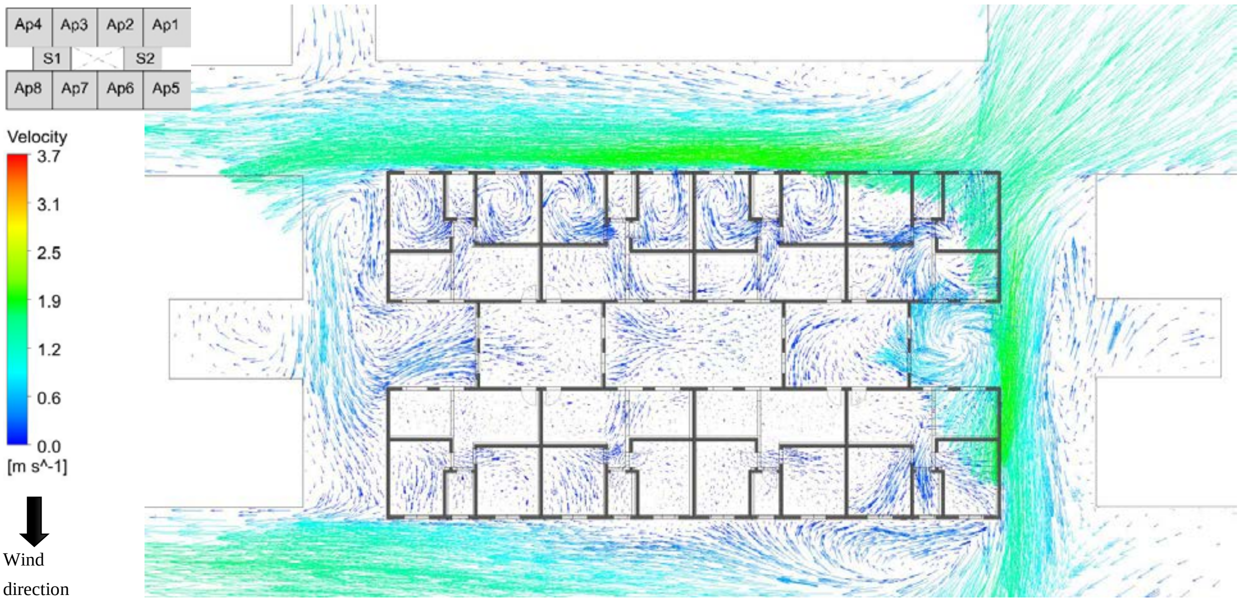


Figure 9. Airflow in the fourth floor apartments at wind attack angle of 0°, obstructed surrounding.

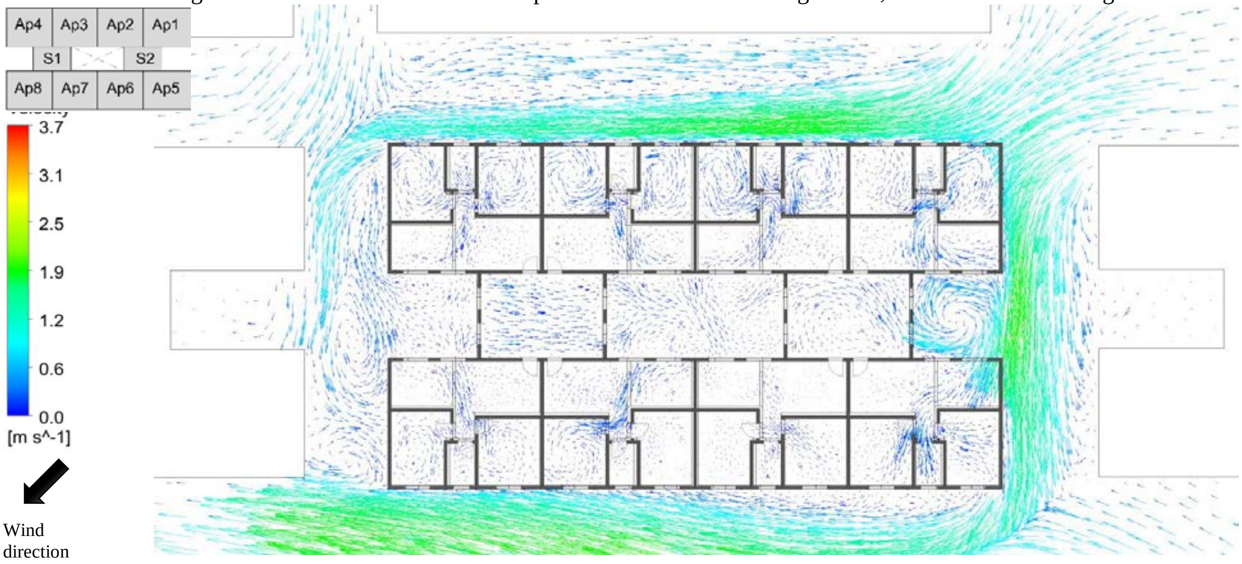


Figure 10. Airflow in the first floor apartments at wind attack angle of 45°, obstructed surrounding.

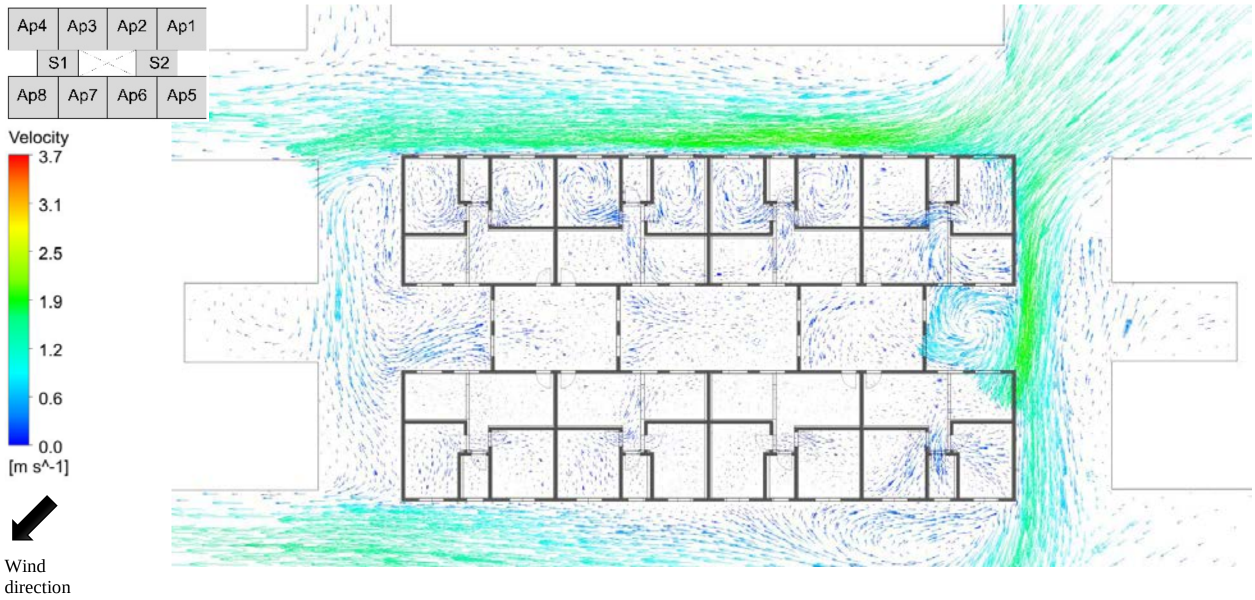


Figure 11. Airflow in the fourth floor apartments at wind attack angle of 45°, obstructed surrounding.

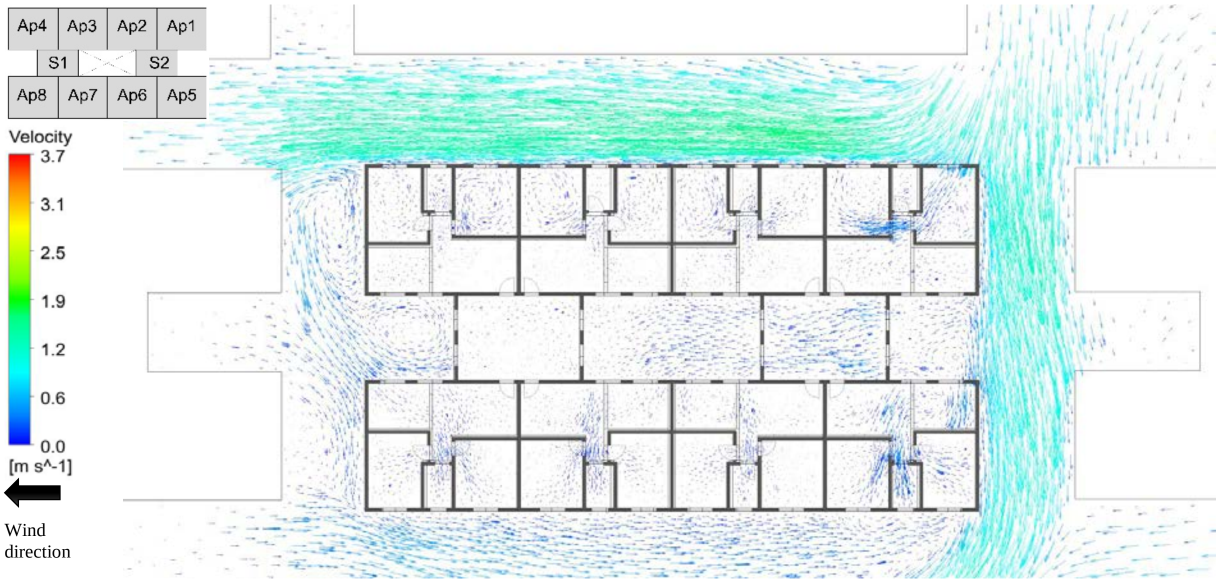


Figure 12. Airflow in the first floor apartments at wind attack angle of 90°, obstructed surrounding.

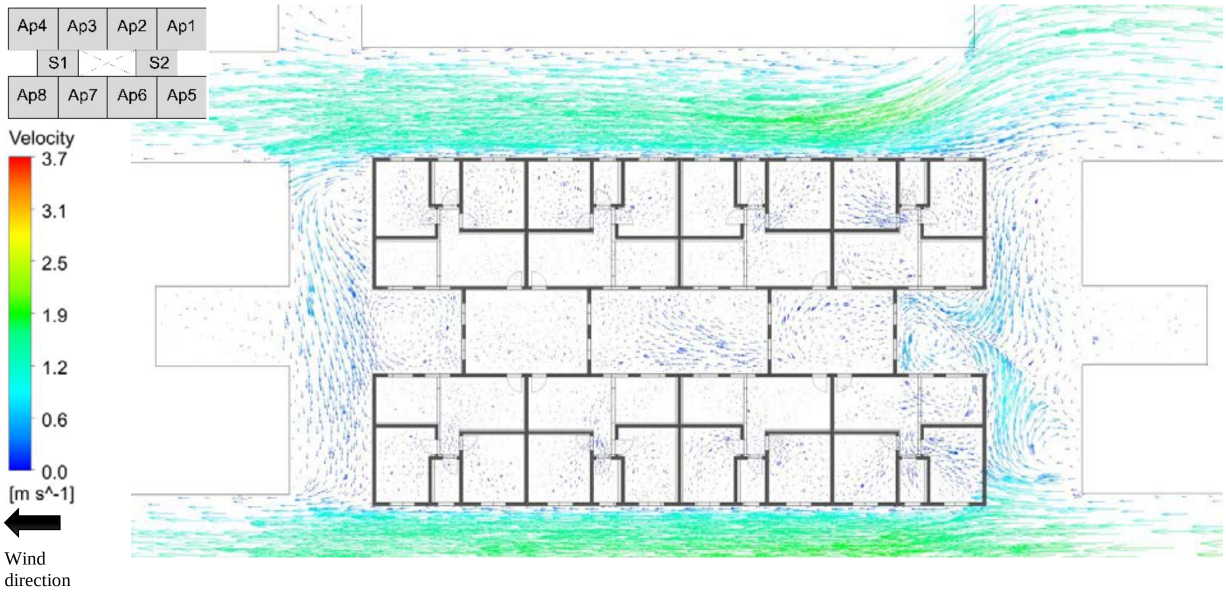


Figure 13. Airflow in the first floor apartments at wind attack angle of 90°, obstructed surrounding.

3.2 Wind speed

Table 3 shows that, on the models with the unobstructed surroundings, the average wind speed at the first floor is lower than at the fourth floor. The models with wind attack angle of 0° and 45° presented the most significant difference, in these scenarios the wind speed at the fourth floor is twice that of the first floor due to the boundary limit profile. In addition, apartments with no windows to windward presented the lowest velocities (7 to 21% lower).

By evaluating the models with the obstructed surroundings it becomes clear that the boundary limit profile and the wind attack have low influence on the average speeds of apartments. This is due to the influence of the surroundings obstruction which causes an average reduction of 38% on the apartments velocities.

Table 3. Average wind speed of first and fourth floor apartments at wind attack angle of 0°, 45° and 90°*.

		Floor	Ap1 [m/s]	Ap2 [m/s]	Ap3 [m/s]	Ap4 [m/s]	Ap5 [m/s]	Ap6 [m/s]	Ap7 [m/s]	Ap8 [m/s]	Floor Avg [m/s]
unobstructed	**0°**	1st	0.22	0.27	0.22	0.23	0.06	0.03	0.05	0.09	0.07
		4th	0.33	0.46	0.43	0.53	0.13	0.10	0.18	0.17	0.18
	45°	1st	0.10	0.21	0.19	0.21	0.12	0.04	0.03	0.10	0.06
		4th	0.19	0.22	0.20	0.70	0.47	0.24	0.11	0.13	0.12
	90°	1st	0.29	0.08	0.05	0.03	0.32	0.07	0.05	0.03	0.04
		4th	0.25	0.06	0.04	0.38	0.45	0.12	0.07	0.10	0.09
obstructed	**0°**	1st	0.11	0.05	0.03	0.10	0.05	0.02	0.03	0.02	0.02
		4th	0.14	0.07	0.03	0.09	0.04	0.04	0.04	0.03	0.03
	45°	1st	0.14	0.08	0.05	0.09	0.07	0.05	0.04	0.10	0.07
		4th	0.18	0.12	0.05	0.08	0.12	0.07	0.06	0.06	0.06
	90°	1st	0.14	0.04	0.02	0.04	0.14	0.03	0.03	0.05	0.04
		4th	0.08	0.05	0.03	0.04	0.11	0.05	0.02	0.02	0.02

Legend:

Text in red= apartments with no windows to windward

Text in black= apartments with at least one window to windward

* The measurement point are indicated in figure 2-b.

4 CONCLUSION

This study addressed the issue of airflow quality on a residential building configured as a "double H", focusing on the effect of surroundings obstruction, wind attack angle and floor level.

The analysis of the airflow around the buildings with unobstructed surroundings indicates that the wind attack angle not only influence the velocity of the income air, but also influences the airflow and the turbulence levels. In addition, the floor level has a strong influence on the incoming velocity on models with unobstructed surroundings due to the boundary limit profile, especially at 0° and 45. Then in the buildings with obstructed surroundings, the velocities were always low and neither the wind attack angle nor floor level show any influence in the wind speed but influence the airflow behaviour.

In relation to the incoming airflow, it is noted that when the airflow is tangent to the windows the ventilation inside the rooms is insufficient. In addition, apartments with windows only at leeward also do not achieve good ventilation.

For these reasons, the "double H” building shape do not present good ventilation on all apartments at any wind attack angle, surroundings obstruction or floor level. This leads to conclude that different options of building shapes should be considered, such as leaving a space between the two “H”. This strategy prevents the airflow from crossing the neighbour’s apartments before arriving at the apartment located leeward on the courtyard; also, it would provide better air circulation.

Another identified issue is that in some cases the incoming air in the living room and kitchen comes from the bathroom, bringing undesired odours. A solution in these cases could be to mirror the apartments position by always placing the living room and the kitchen windows at the windward position.

The findings of this work can contribute to the quality of the built environment in the country, since it evaluates a recurrent format in residential buildings in Brazil, and indicates solutions to the identified problems. In this way, it gives subsidy for the design of new buildings with proper ventilation.

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