Study of Natural Ventilation for a Modular Façade System in Wind Tunnel Tests

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ABSTRACT: Wind tunnel tests are a reliable tool to determine the effect of natural ventilation on buildings. This paper presents results of wind tunnel tests conducted to evaluate the influence of ventilation modules positioning on a façade system. Modules positioning was modified, resulting in different façade configurations. The tests were carried out with the use of a model, varying the position of the ventilation modules in the façade configuration. The cases tested were six ventilation modules positioned below the window-sill (ventilated window-sill), and three ventilation modules positioned above and below the façade. The façade system proposed was movable and interchangeable so that the same basic model could be used to test the possibilities for ventilation. Wind speed measurements were taken inside and outside the model for the different façades configurations to evaluate the best performance in relation to natural ventilation. Single-sided and Cross ventilation were considered for wind speed measurements. Results show the use of six ventilation modules positioned below the window-sill, forming a "ventilated window-sill" is the best solution in terms of natural ventilation.

Keywords: Natural ventilation, Wind tunnel tests, Ventilation modules, Modular façade system.

1 INTRODUCTION

Natural ventilation is the movement of air through specific building openings due to the natural forces produced by wind and temperature differences. Nowadays natural ventilation has gained prominence, because the correct use of it can reduce the energy consumption for cooling systems and improve the thermal comfort of users. The two fundamental principles of natural ventilation are stack effect and wind driven ventilation.

About wind velocities Olgyay (1998) e Evans (1957) point out that air velocities up to 0.25 m/s are imperceptible, not causing cooling sensation in users. For these authors, speed values between 0.25 and 0.50m/s are pleasant and provide fresh feeling. Evans and Schiller (1994) point out that values up to 0.5m/s have no cooling effect, and above this value it originates a perceptive movement for cooling effect.

The air velocity required for comfort is based on the health of users, as the supply of oxygen and removal of contaminants. The maximum speed of indoor air is defined by factors such as physiological comfort, type of building and use. For office and commercial buildings, the limit is

0.8m/s, for industrial spaces 1.5m/s is acceptable this values to assist in the removal of toxic substances, heat or other harmful conditions. For residential buildings the maximum speed indoor air recommended is 1 m/s (Military Handbook, 1990).

For ventilation studies, wind tunnel tests are a reliable tool for determining the effects of wind loads on civil engineering structures and also to determine the influence of natural ventilation in buildings, which is the specific purpose of this research. The natural ventilation, renewing the air in a closed environment without using mechanical elements, can lead to energy savings by avoiding air conditioning system use and, in addition, provide air quality.

In a wind tunnel, speed and wind direction are controlled and small models are used to simulate the natural ventilation of buildings. There are some studies in this area in terms of measurements of velocity, pressure and air change rate to analyse the characteristics of cross ventilation (Murakami et al., 1991). Jiang et al. (2003) present a comparison of results obtained from wind tunnel tests and numerical simulation of airflow. This type of simulations can also be considered to allow the study of natural ventilation in buildings.

The wind tunnel tests performed with reduced scale models are important for:

- Increasing the reliability and effectiveness of construction and also reducing the costs of projects;
- Allowing evaluation of the influence of other buildings, surroundings and ground in the ventilation of buildings;
- Evaluating the quality of indoor air in relation to the dispersion of pollutants and contaminants;
- Allowing a more efficient study of the ventilation of indoor environment and optimize the distribution of windows for a better environmental comfort (in the case of this research).

Furthermore, wind tunnel tests can be used, for example, to study cases as direct cross-ventilation and the ventilation positioned downwind or windward and also the positioning of the opening to the wind (positioned at normal or parallel to the flow direction of ventilation).

The definition of the model characteristics is fundamental to the realization of wind tunnel tests. The phenomenon observed in the model and in the prototype (the real building) has to be equivalent, if the rules of physics and conditions contour are similar. The model and the building are not the same, but the relationship between the parties, height and length ratio allows recognizing the prototype in the model and vice-versa (Cóstola, 2006).

This paper presents results of wind tunnel tests conducted to evaluate the influence of ventilation modules positioning on a façade system. The modules positioning was modified, resulting in two different façade configurations.

2 METHODOLOGY

2.1 The wind tunnel

The wind tunnel (atmospheric boundary layer) of the Laboratory of Environmental Comfort and Applied Physics, Faculty of Civil Engineering, Architecture and Urbanism, UNICAMP operates with an axial fan sucking air and was used in this work. Figures 1 and 2 respectively present a view from the exterior of the axial fan and a general illustration of the wind tunnel.

The wind tunnel used has a cross-section of the chamber test of 0.9m width by 0.8m height with an area of 0.72m². Inside the wind tunnel, turbulence is generated by means of a roughened surface and zero pressure gradient (due to the need to generate a turbulent boundary layer).

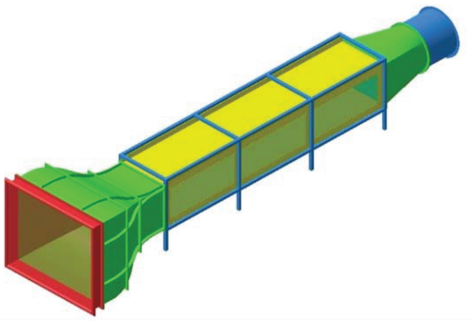


Figure 1. Wind Tunnel - UNICAMP. Figure 2. Wind Tunnel Overview

Besides these features the wind tunnel has other details, such as:

- Total length of the tunnel of 9.03m;
- Length of the test section of 4.80 m;
- Diameter of the fan blades of 1.20 m, in a total of 16 blades; and
- Wind tunnel output diameter of 1.25m.

2.2 Definition of the model

As the dimensions of the test section of the wind tunnel are 0.9m in width by 0.8m height, with a total cross-sectional area of 0.72m², the rate of the obstruction test section is recommended to be 5% acceptable up to 7%. Therefore, the model should block up to 7% area, namely the frontal area of the model, perpendicular to the wind, should be maximum 0.05m². There are no restrictions of dimensions in the horizontal direction along the wind tunnel.

The model was built in the scale 1:20, with dimensions of 0.16m in height, 0.28m in width and 0.28m length and the frontal area is 0.045m². The cross-sectional obstruction of the wind tunnel is 6.3%. Table 1 presents the dimensions of the model and real dimensions.

Table 1. Dimensions of the Model.

Measures	Real Dimensions (m)	Models Dimensions (m)
Height	3.20	0.16
Width	5.65	0.28
Length	5.65	0.28
Scale		1:20
Section area of the wind tunnel (m^2)		0.72
Frontal area of the model (m^2)		0.045
Cross-sectional obstruction of the wind tunnel (%)		6.3

The model was constituted by wood paper with thicknesses of 1, 2 and 3 mm and connected by PVA glue (Figures 3 and 4).

Figure 3. Model. Figure 4. Open Model.

Afterwards, the parts in acrylic (variations of facades with 2.5m x 2.5m and 2mm thickness) were cut in the Laboratory of Automation and Prototyping for Architecture and Construction (LAPAC), Faculty of Civil Engineering, Architecture and Urbanism (FEC) UNICAMP (Figure 5).

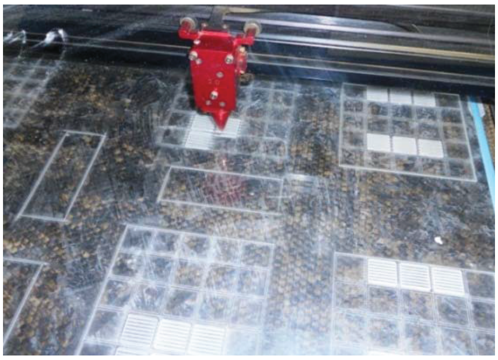


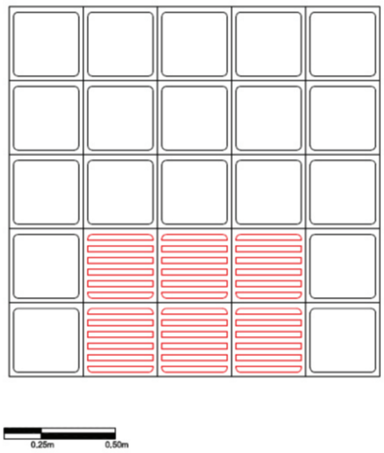
Figure 5. Prototypes confection of the facades in acrylic, then creasing the cuts are started on the laser cutter.

The facades proposed are mobile and interchangeable in order to take advantage of the same base model to test possibilities of ventilation. Two variations of facade positions, whose characteristics will be presented below, were built. Each ventilation module has dimensions of 0.50 x 0.50 m.

The cases tested were six ventilation modules positioned below the window-sill (ventilated window-sill) (01A), and three ventilation modules positioned above and three below the façade (01B). Each of these cases was tested twice, considering the door for ventilation exit open or closed (Figures 6, 7 and 8).

The purpose for these tests was to evaluate the internal and external speeds for each configuration of facade presented earlier. These tests were important to emphasize how such variations influence to obtain more efficient natural ventilation. The most important in the velocity measurements in the wind tunnel in this research are the indoor values relative to the speed of incidence on the facade.

To measure the internal speeds of the model in the wind tunnel, three sensors hot wire anemometer thumbnails were installed inside, through holes in the bottom. The internal sensors (P2, P3 and P4) were positioned at a height of 0.80m from the floor in the scale of 1/20, which corresponds to a person sitting. In addition, two external sensors were installed on the outlet air opening (door) (P5 and P6), in order to obtain the wind speed when leaving the model (Figure 9).



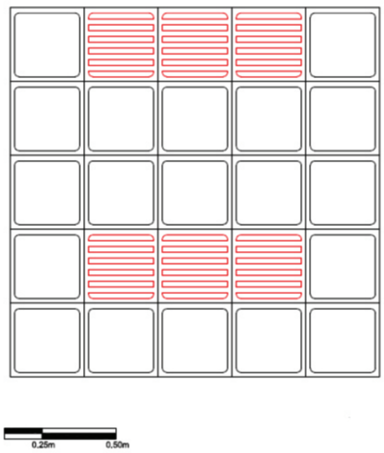


Figure 6. Case 1A: Ventilated window-sill. Figure 7. Case 1B: Three ventilation modules positioned above and three below the façade.

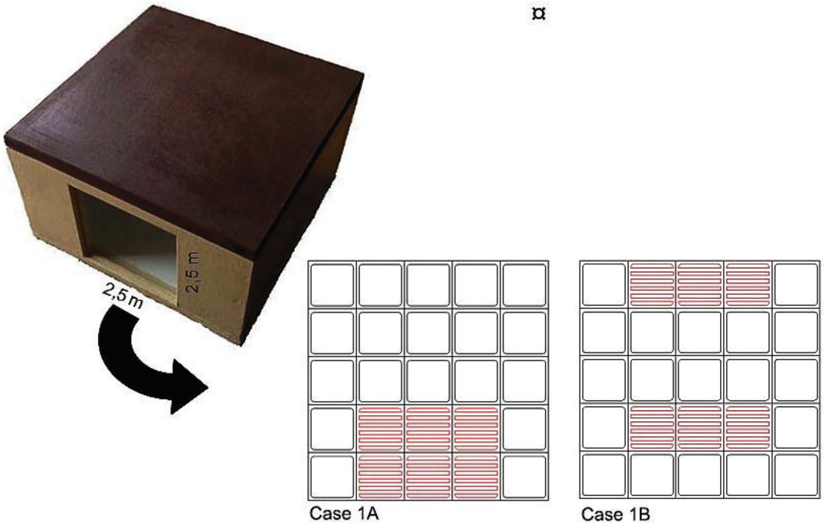
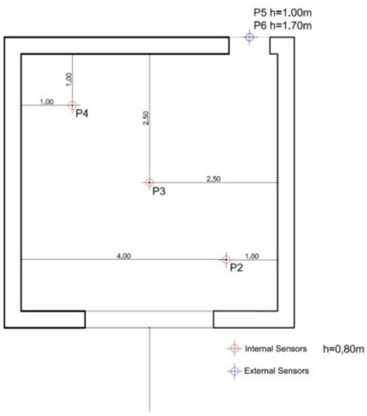


Figure 8. Configuration of facades to wind tunnel tests.

In the main model facade was installed the sensor (P1) for the purpose of measuring the speed of the external wind before reaching the physical model The Figure 10 presents the model positioned inside the wind tunnel with the front sensor (P1).



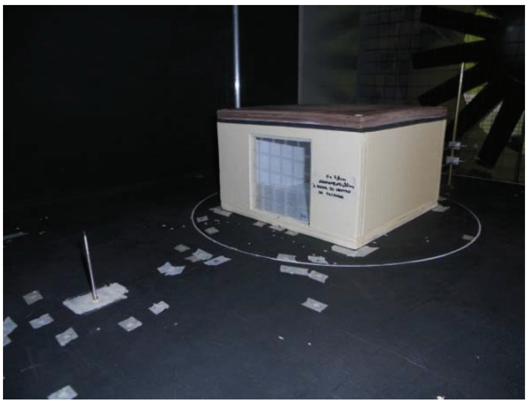


Figure 9. Positioning of sensors in the model. Figure 10. Model positioned inside wind tunnel.

3 RESULTS

Measurements were performed to compare the speeds of the two variations of facades studied in order to determine which one offers the best performance relative to natural ventilation. Internal and external speeds were quantified by tests in the wind tunnel.

The results of wind tunnel tests were performed by comparing internal speeds and the wind speed of incidence, close to the facade in order to determine the configuration that offers the best ventilation conditions.

3.1 Measurements of wind speed

Tables 2 and 3 present values of the average air velocity at specific points observed in the model described previously (three internal and three external points), according to the configuration of the façade.

About the speed measured inside and outside of the model:

- V1 = Wind speed at the point P1 to the facade 6m and 1.55m in height;
- V2 = Wind speed at point P2 in the edge to 0.80m in height;
- V3 = Wind speed at the midpoint P3 to 0.80m in height;

- V4 = Wind speed at point P4 in the edge to 0.80m in height;
- V5 = Wind speed at point P5, in the air outlet (door) to 1.00m in height;
- V6 = Wind speed at point P6, in the air outlet (door) to 1.70m in height.

Table 2. Case 01A: With and without cross ventilation - Average Speeds by Frequency

Frequency (Hz)	Average Speeds by Frequency (m/s)											
	V1		V2		V3		V4		V5		V6	
	1AO	1AC	1AO	1AC	1AO	1AC	1AO	1AC	1AO	1AC	1AO	1AC
3	1.67	1.24	0.61	0.59	0.78	0.59	0.64	0.57	0.84	-	0.94	-
5	2.39	2.42	0.65	0.59	0.98	0.59	0.79	0.57	1.29	-	1.49	-
7	3.91	3.38	0.81	0.59	1.88	0.59	1.12	0.57	2.10	-	2.25	-
9	5.33	4.83	1.14	0.59	2.63	0.60	1.35	0.57	2.82	-	2.94	-
11	6.05	5.97	1.53	0.60	2.88	0.61	1.44	0.58	3.23	-	3.35	-
13	7.06	7.20	1.64	0.60	3.41	0.64	1.76	0.58	3.81	-	3.94	-

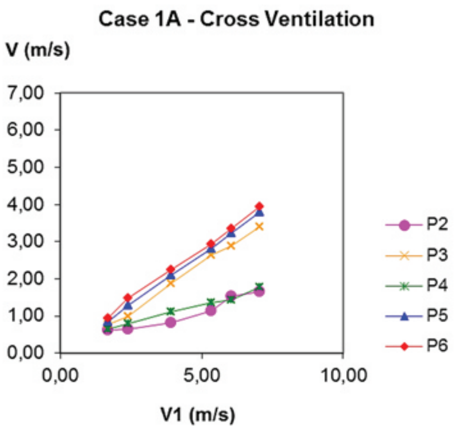
Case 01A:
1AO= Case 01A with cross-ventilation (open door)
1AC= Case 01A without cross-ventilation (closed door)

Table 3. Case 01B: With and without cross ventilation - Average Speeds by Frequency

Frequency (Hz)	Average Speeds by Frequency (m/s)											
	V1		V2		V3		V4		V5		V6	
	1BO	1BC	1BO	1BC	1BO	1BC	1BO	1BC	1BO	1BC	1BO	1BC
3	1.48	1.44	0.64	0.59	0.74	0.59	0.59	0.57	0.78	-	0.90	-
5	2.44	2.26	0.69	0.59	0.85	0.59	0.67	0.58	1.28	-	1.52	-
7	3.63	3.78	0.86	0.60	1.41	0.60	0.72	0.58	1.91	-	2.19	-
9	5.51	5.48	1.10	0.60	2.15	0.61	0.85	0.59	2.75	-	3.06	-
11	5.34	4.96	1.37	0.61	1.83	0.61	0.89	0.59	2.87	-	3.26	-
13	7.41	6.74	1.46	0.62	2.66	0.64	1.13	0.60	3.87	-	4.29	-

Case 01B:
1BO= Case 01B with cross-ventilation (open door)
1BC= Case 01B without cross-ventilation (closed door)

For a better analysis of the results were prepared graphs showing the air velocities inside and outside the model studied as a function of the speed of 6m from façade and height of 1.55m (V1). It is observed in most cases, for cross ventilation, a linear trend in velocity variation in the measured points. The highest values were observed in the velocities measured for points outside the model, positioned at the outlet air opening (P5 and P6) (Figures 11 and 12).



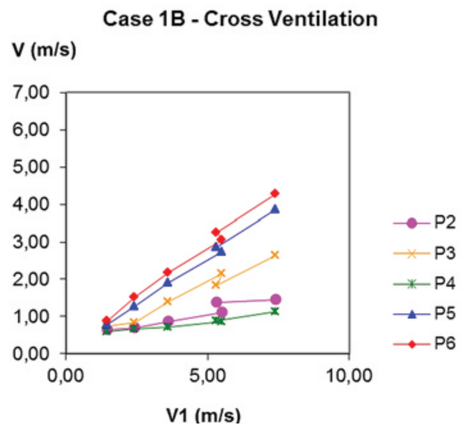
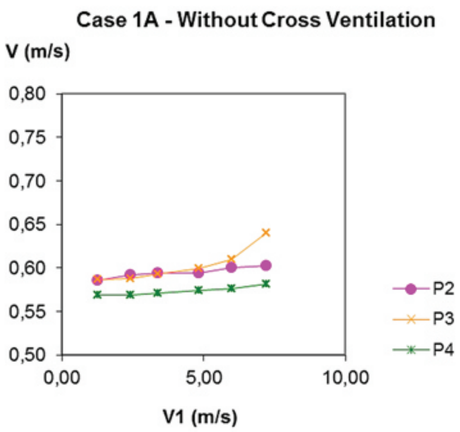


Figure 11. Case 1A with cross ventilation: Speeds in internal points and speed on the facade (V1). Figure 12. Case 1B with cross ventilation: Speeds in internal points and speed on the facade (V1).

For these cases, that present the elements of grid positioned vertically (1A and 1B), the effective opening area on the facade was $0.61m^2$ and the area of door was $1,45m^2$, thus the area of the air outlet is higher than the input. According to Chávez and Freixanet (1995), the larger the size of the air outlet opening in comparison with the input, the greater the acquired wind speed; this may explain the fact that higher speeds are positioned at the points air outlet port (P5 and P6).

Among the points measured inside the model, the one positioned at the center (P3) resulted in higher values of speed for the cases analyzed, followed by P2 and P4 points values.

For Point P2 located inside the model, on the edge next of the façade, the lowest values of speed were observed for the Case 1B. For the P5 point (the lowest point of the air outlet) were observed lower speeds for Case 1B. Based on the cases without cross ventilation, in other words, with the model door closed, the same results were observed practically for the evaluated facades (Figures 13 and 14).



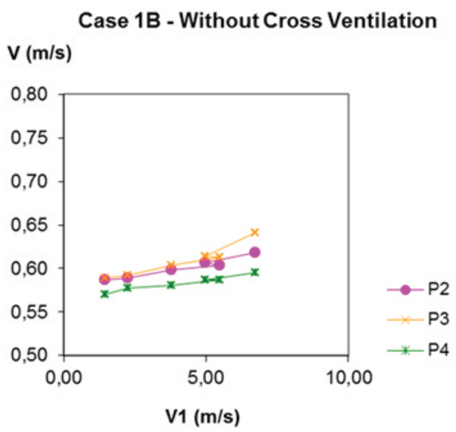


Figure 13. Case 1A: Without cross ventilation: Speeds in internal points and speed on the facade (V1). Figure 14. Case 1B: Without cross ventilation: Speeds in internal points and speed on the facade (V1).

4 CONCLUSIONS

Based on the results obtained by the wind tunnel tests it was observed that the best configuration of facade in terms of natural ventilation was a ventilated window-sill. This solution was better than ventilation modules positioned separately above and below the façade.

It was observed that the cross ventilation provides higher speed and a better internal global distribution of air inside. Probably, the height difference between the openings of the second solution (ventilation modules positioned separately) was insufficient to improve ventilation.

For cases with openings in only one of the facades (without cross ventilation), the ventilation is low, about the same regardless of the type of solution. Probably, the average speed of the internal wind will not change significantly with increasing the size of the inlet opening for cases without cross ventilation. These results prove the necessity of having openings opposite or adjacent to occur better natural ventilation.

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