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Different module placements in a modular façade system for natural ventilation

Helenice Sacht[a]*, Luis Bragança[b], Manuela Almeida[b] and Rosana Caram[c]

[a]Federal University of Latin American Integration, Foz do Iguaçu 85867-970, Paraná, Brazil
[b]University of Minho, School of Engineering, Guimarães 4804-533, Portugal
[c]University of São Paulo, São Carlos 13566-590,São Paulo, Brazil

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Abstract

Nowadays natural ventilation has gained prominence because its correct use can reduce energy consumption for cooling systems and improve thermal comfort among users. In this paper, we report on the modelling initiative, based on the wind tunnel tests that were carried out for the determination of the influence of natural ventilation in buildings. Indeed, the renewal of air in a closed environment without using an air conditioning system with mechanical elements can lead to energy savings and, in addition, provide air quality. The wind tunnel tests were carried out by varying the positioning of six ventilation modules in the façade system configuration. The modules were positioned below the window-sill (ventilated window-sill) as well as separately above and below the façade. The 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. The results supported the positioning of the six ventilation modules below the window-sill, forming a "ventilated window-sill" as the most effective natural ventilation solution.

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Keywords: Façade; natural ventilation; wind tunnel tests

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1. Introduction

Ventilation has a significant impact on several important human responses. Low ventilation rates may result in increased concentration of indoor generated pollutants, which may be associate with sick building syndrome

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* Corresponding author. Tel.: 0055459800-2482
E-mail address:nicesacht@yahoo.com.br

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symptoms, comfort (perceived air quality), health effects (inflammation, infections, asthma, allergy) and productivity. Ventilation requirements receive major attention in building regulations across Europe. The ventilation standards tend to cluster around common values for recommended ventilation rates. For example, the Nordic countries have adopted the minimum requirement of 0.5 h^{-1} for the whole building ventilation rates. Some other countries have also adopted the rates greater than 0.3 h^{-1}. In reality, ventilation is often poor, resulting in increased concentration of pollutants and hence exposure to health risk (Dimitroulopoulou, 2012). The two fundamental principles of natural ventilation are stack effect and wind driven ventilation.

In 1990s, the early studies were conducted in the Helsinki Metropolitan Area, indicating the importance of natural ventilation research in Finland. The investigation was performed among the 473 occupants within the 242 dwellings (houses and apartments), with the different ventilation systems, in order to evaluate the occurrence of sick building syndromes and the perceptions of poor indoor air quality. Simultaneously, a two-week period of indoor air quality monitoring was performed. The main conclusions were as follows (Ruotsalainen et al., 1991):

- The most common perception was stuffiness;
- 22% of the occupants perceived that the ventilation rate of the bedroom was often insufficient;
- 46% of the occupants felt the bedroom air was sometimes or often stuffy in the mornings during the two weeks;
- 40% of the occupants felt the bedroom air was usually too dry in winter-time;
- At least one day over the two-week period, B Half of the occupants reported that they had had sneezing (51%) and/or nasal congestion (50%);
- About one third of the occupants expressed nasal discharge (34%), nasal dryness (33%), dryness or itching of the skin (36%), headache or migraine (31%) and lethargy, weakness or nausea (35%); and
- 25% of the occupants reported that they had had cough and 19% dryness, irritation or itching of the eyes, whereas only 6% of the occupants expressed breathlessness on at least one day during the two weeks.

The air velocity required for comfort is based on the health of users, the supply of oxygen and the removal of contaminants. The maximum speed of indoor air is defined by factors such as physiological comfort, building type and use. For office and commercial buildings, the limit is 0.8m/s. For industrial spaces, 1.5m/s is acceptable to assist in the removal of toxic substances, heat or other harmful conditions. For residential buildings, the maximum speed indoor air recommended is 1.0 m/s (Military Handbook, 1990).

Wind tunnel tests are a reliable tool for ventilation studies and determining the influence of natural ventilation in buildings. Natural ventilation, i.e. renewing air in a closed environment without using air conditioning system with mechanical elements can lead to energy savings and, in addition, provide air quality. 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 the 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; and
- allowing the more efficient study of the ventilation of indoor environments and optimising the distribution of windows for better environmental comfort (i.e. like in the case of this study).

Wind tunnel tests can also be used to study cases, such as direct cross-ventilation, ventilation positioned downwind or windward and the opening positioned to the wind (positioned at normal or parallel to the flow direction of ventilation). For advancing energy efficiency, productivity and user health in buildings, engineering innovations are necessary, such as increasing natural ventilation performance and improving ventilation effectiveness. In turn, this paper reports on the conduct and results of the wind tunnel measurement. The study on the influence of the ventilation modules positioning on a façade system was carried out. The positioning of the ventilation modules was modified in the façade configuration in order to evaluate the results as the air velocity at specific points observed in a model.

2. Methodology

2.1. 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. It was used for this study. Figures 1 and 2 respectively present a view from the exterior of the axial fan and a general illustration of the wind tunnel.

Fig. 1. Wind tunnel - UNICAMP.

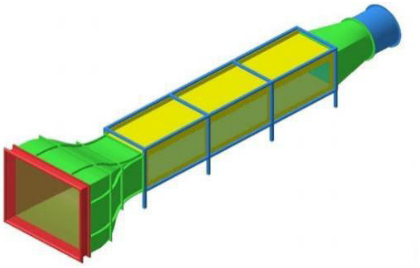

Fig. 2. Overview of a wind tunnel.

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). 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. 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 on 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 the real dimensions.

Table 1. Dimensions of the model.

Measures	Real dimensions (m)	Model's 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 (m2)		0.72
Frontal area of the model (m2)		0.045
Cross-sectional obstruction of the wind tunnel (%)		6.3

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

Fig. 3. Model.

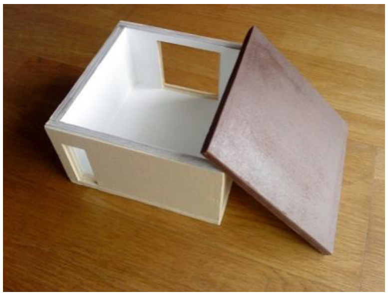

Fig. 4. Open model.

Afterwards, the parts in acrylic (variations of the 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).

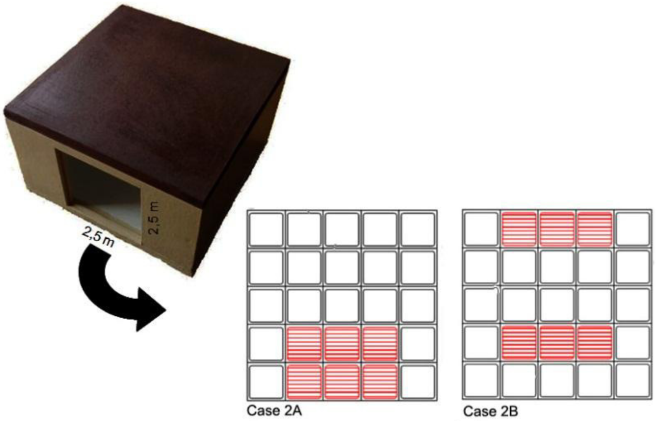

Fig. 5. Configuration of the facades for the wind tunnel tests.

The facades are mobile and interchangeable in order to take advantage of the same base model to test possibilities of ventilation. The two variations of the facade positions (see the characteristics below) were built. Each ventilation module has the dimensions of 0.50 x 0.50 m. The cases tested were the six ventilation modules positioned below the window-sill (ventilated window-sill) (02A) as well as the three ventilation modules positioned above the façade and the three ventilation modules positioned below the façade (02B). Each of these cases was tested twice, considering the door for ventilation exit open or closed (Figure 5).

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

To measure the internal speeds of the model in the wind tunnel, the three sensors hot wire anemometer thumbnails were installed inside, through the 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, the 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 6).

In the main model, the sensor (P1) was installed on the facade for the purpose of measuring the speed of the external wind before reaching the physical model. The Figure 7 presents the model positioned inside the wind tunnel with this front sensor.

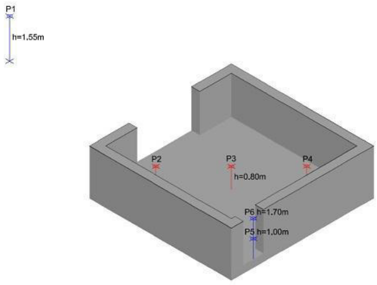

Fig. 6. Positioning of the sensors in the model.

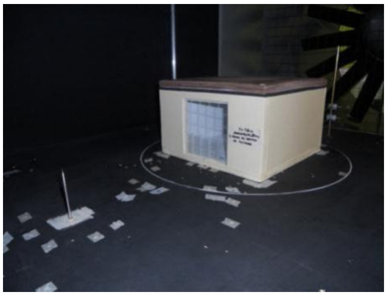

Fig. 7. Model positioned inside the tunnel.

3. Results

The measurements were performed to compare the speeds of the two variations of the facades studied in order to determine which one offers the best performance relative to natural ventilation. The internal and external speeds were quantified by the tests in the wind tunnel. The results of the wind tunnel tests were achieved by comparing the 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. Wind speed measurements

Tables 2 and 3 present the values of the average air velocity at specific points observed in the model (the three internal points and the three external points), according to the configuration of the façade. The speed measurement inside and outside the model is clarified as follows:

- 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 02A: With and without cross ventilation - Average speeds by frequency

Frequency (Hz)	Average speeds by frequency (m/s)											
	V1		V2		V3		V4		V5		V6	
	2AO	2AC	2AO	2AC	2AO	2AC	2AO	2AC	2AO	2AC	2AO	2AC
3	1,25	1,24	0,81	0,59	0,75	0,59	0,60	0,57	0,95	-	0,97	-
5	2,45	2,27	1,18	0,59	1,28	0,59	0,73	0,57	1,89	-	1,87	-
7	3,74	3,77	1,34	0,60	2,00	0,59	1,08	0,57	2,70	-	2,69	-
9	5,06	5,04	1,33	0,60	2,63	0,60	1,59	0,58	3,39	-	3,41	-
11	6,26	6,00	1,64	0,60	3,36	0,61	1,90	0,58	4,23	-	4,24	-
13	7,30	6,98	1,80	0,61	3,89	0,64	2,28	0,58	4,99	-	5,02	-

Case 01A:
2AO= Case 02A with cross-ventilation (open door)
2AC= Case 02A without cross-ventilation (closed door)

Table 3. Case 02B: With and without cross ventilation - Average speeds by frequency

Frequency (Hz)	Average speeds by frequency (m/s)											
	V1		V2		V3		V4		V5		V6	
	2BO	2BC	2BO	2BC	2BO	2BC	2BO	2BC	2BO	2BC	2BO	2BC
3	1,28	1,29	0,76	0,59	0,68	0,59	0,60	0,57	0,89	-	1,00	-
5	2,41	2,30	1,09	0,60	0,98	0,60	0,67	0,58	1,73	-	1,88	-
7	3,86	3,98	1,01	0,61	1,79	0,61	0,81	0,59	2,67	-	2,86	-
9	5,10	4,76	1,16	0,61	2,36	0,62	0,93	0,59	3,49	-	3,71	-
11	6,17	5,65	1,40	0,62	2,72	0,66	1,12	0,60	4,17	-	4,41	-
13	6,73	7,43	1,71	0,64	2,77	0,72	1,24	0,61	4,68	-	4,97	-

Case 02B:
2BO= Case 02B with cross-ventilation (open door)
2BC= Case 02B without cross-ventilation (closed door)

For the analysis of the results, the graphs were prepared for showing the air velocities inside and outside the model as the function of the speed, of 6m from the façade and the height of 1.55m (V1). For cross ventilation, a linear trend in the velocity variation in the measured points is being observed in most cases. The highest values were observed in the velocities measured for the points outside the model, positioned at the outlet air opening (P5 and P6) (Figures 8 and 9).

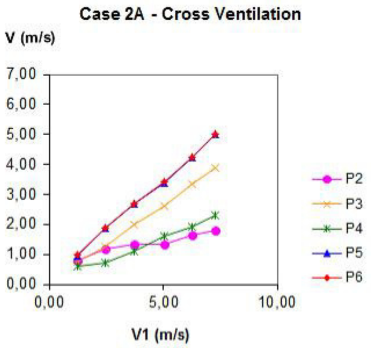

Fig. 8. Case 2A with cross ventilation: the speeds at the internal points and the speed on the facade (V1).

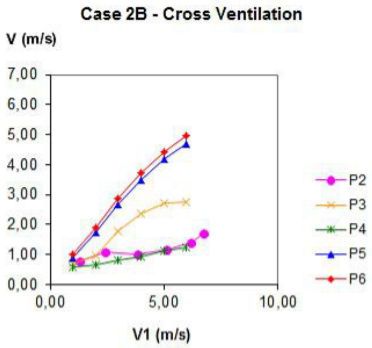

Fig. 9. Case 2B with cross ventilation: the speeds in the internal points and the speed on the facade (1).

For these cases, that present the elements of the grid positioned horizontally (2A and 2B), the effective opening area on the facade was 0.82m² and the area of door was 1,45m². 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 is in comparison with the input, the greater the acquired wind speed is. This may explain a fact that the higher speeds were positioned at the points air outlet port (P5 and P6).

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

For Point P2 located inside the model, on the edge next of the façade, the highest values of the speed were observed for the Case 2A. For Point P5 (the lowest point of the air outlet), the lower speeds were observed for Case 2B. Based on the cases without cross ventilation, in other words, with the model of the door closed, the near results were observed for the evaluated facades (Figures 10 and 11).

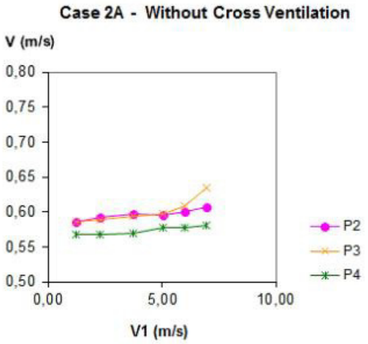

Figure 10. Case 2A: Without cross ventilation: the speeds at the internal points and the speed on the facade (V1).

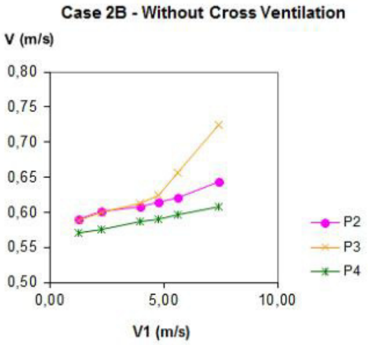

Figure 11. Case 2B: Without cross ventilation: the speeds at the internal points and the speed on the facade (V1).

4. Conclusion

Natural ventilation in buildings is important to maintain indoor air quality, to provide thermal comfort by means of air movement, to cool the mass of the building during the night and to warm the mass of the building during the day. The choices of natural ventilation solutions also depend on the detailed analysis of local climate conditions.

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

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

For the cases with the openings in only one of the facades (without the cross ventilation), the ventilation was low, about the same regardless of the solution type. It is probably so that the average speed of the internal wind does not change significantly with the increasing of the size of an inlet opening without cross ventilation. Thus, this study points out to the necessity of having openings opposite or adjacent in order to ensure better natural ventilation.

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