NUMERICAL ANALYSIS OF WINDOWS AND FURNITURE INFLUENCE ON THE AIRFLOW IN NATURALLY VENTILATED OFFICE ENVIRONMENTS

Flávio Bomfim Mariana, flavio.mariana@gmail.com
Arlindo Tribess, atribess@usp.br
Escola Politécnica da Universidade de São Paulo, Av. Prof. Luciano Gualberto, travessa 3 nº 380 CEP 05508-970 – São Paulo – SP

Abstract. *Among the spread of sustainable concept it has been found an increase interest on systems that have low or zero energy consumption. Similarly, there is a growing concern with indoor environmental quality. Natural ventilation systems can match these expectations, but detailed analysis on the airflow conditions is necessary to obtain an environment which provides good comfort conditions. The present report studied the influence of furniture on the airflow in a naturally ventilated office, as well as the influence of the window geometry, with computational fluid dynamics. Results showed that the window geometry has a more significant influence on the airflow distribution, and consequently, also on the temperature field, especially on the leeward side of the office. Maxim-air windows direct the airflow towards the ceiling, which helps to increase the air velocity all over the environment. Vertical sliding windows reduce in 32% the airflow rate and direct the airflow more horizontally, worsening environmental conditions. The higher partitions make the velocity field less uniform, prejudicing the heat removal by forced convection and increasing the presence of thermal plumes due to natural convection. Offices with vertical sliding windows were more sensible to the variation of partitions height, mainly due to the less intense velocity field. In offices with maxim-air windows, the 0.90m and 1.10m height partitions presented similar results, permitting the use of 1.10m height partitions to enhance occupant privacy without jeopardizing the environmental conditions. Architects and engineers can use these tools to enhance the office environment design.*

Keywords*: Natural Ventilation, CFD, Thermal Comfort, Office Buildings*

1. INTRODUCTION

The indoor environment ventilation with external air intake must provide a proper level of indoor air quality, removing and diluting the contaminants of these environments (ASHRAE, 2007a; ABNT, 2008a) and providing conditions for thermal comfort (ASHRAE, 2004; ISO 7730, 2005; ABNT, 2008b).

In office buildings it can be easily found indoor environments ventilation using air conditioning systems, which demand energy for its operation. On the other hand, when using natural ventilation there is no energy consumption, since the ventilation system is composed by openings in the façade. It allows the use of natural wind resources to ventilate indoor environments, helping the pollutants dispersion, as well as obtaining the thermal comfort conditions for the occupants. The whole process of external air intake, blowing and exhaustion is realized without the need of mechanical equipment, like ventilators for instance.

Despite that, in many situations, due to internal loads and climactic conditions, the use of natural ventilation is not appropriate (CIBSE, 2005). For the correct use of this system, initially it is necessary perform a detailed analysis for the viability of the use of the natural resources, its potentialities and limits. Furthermore, with the dissemination of the sustainable development concept it has been verified a significant rise on the interest for systems that has low or zero energy consumption.

On bibliography it has been verified the existence of a significant quantity of projects that analyze the natural ventilation in very specific situations, almost like case studies, as the projects of Alloca et al (2003), Liping and Hien (2007) and Costa (2009). In general, projects that analyze the application of natural ventilation in buildings focus the analysis of external parameters , such as the variation of wind speed (Gratia et al, 2004), the direction of wind incidence (Cheung and Liu, 2011) or even how external constructions can affect the characteristics of wind resources available in a determined place (Prata, 2005).

On the other hand, the analysis of the effects on natural ventilation conditions caused by internal parameters such as furniture is much less common in literature, being usually found only qualitative references of the subject. For instance, it is said that furniture resists to indoor airflow in such a way that could even deviate the main air stream (Etheridge and Sandberg, 1996), and also that furniture should be kept as low as possible on the ventilated environment (Kendrick et al, 1998 and CISBE, 2005). Another example of qualitative reference is that transfer grilles should be installed when there are ceiling high partitions in naturally ventilated environments (CIBSE, 2005).

Function of these, in the present work it has been analyzed the influence of furniture and façade openings on the natural ventilation conditions in office environments, varying the partitions height and windows geometry, in order to verify their influence on the intensity and direction of the air stream in a office environment using computational fluid dynamics (CFD).

2. METHOD

On the following sections one can found a description about some relevant aspects of the building model and furniture considered on the numerical simulations, the modeling process, the physics involved in the analysis and how it has been approached by the numerical solver, as well as mesh test results.

2.1 The building

The most commonly building plans found in the city of São Paulo are the squared and the rectangular ones (Marcondes, 2010). The plans have approximately 1.000m², being about 70% of this area destined to offices and 30% to common areas. In general, rectangular plans are more proper for the utilization of natural ventilation (CIBSE, 2005), in a way that this type of plan was adopted in the present work, with the dimensions indicated on Fig. 1.

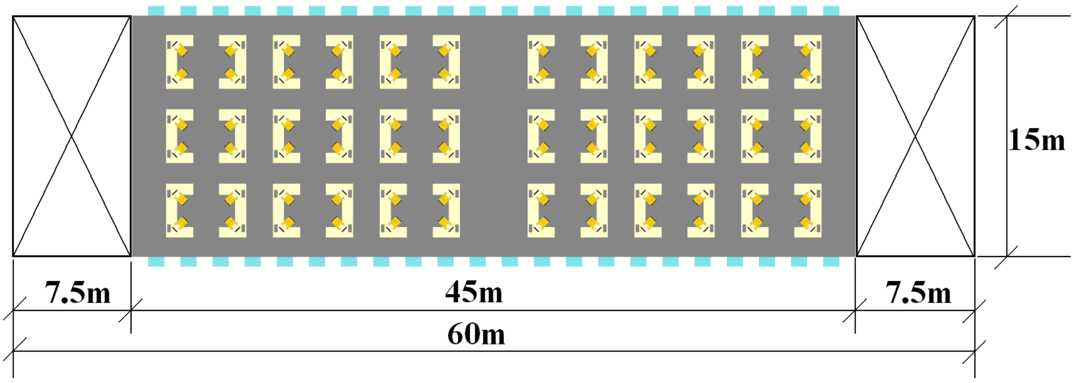


Figure 1. Geometry plan view.

Another relevant element of natural ventilation systems is the geometry adopted for the openings. CIBSE (2005) standard shows several geometries that can be used with this system, but on the literature only a few geometries were analyzed: top-hung, vertical sliding and maxim-air. From these, the maxim-air and vertical sliding were chosen because the first one is very suitable for naturally ventilated environments, since it creates two opening areas, and the second one provides a very large effective opening area. Figure 2 shows these opening geometries.

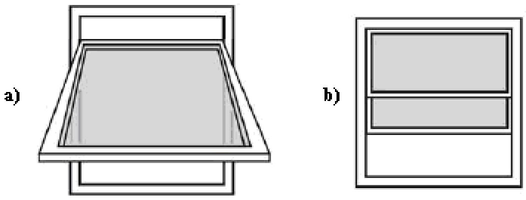


Figure 2. (a) Maxim-air and (b) vertical sliding window geometries (CIBSE, 2005).

2.2 Furniture

A working station is composed essentially by five elements: working desks, cabinets, partitions, chairs and accessories. From these, it was analyzed the influence of the partitions, considering the heights of 0.90m, 1.10m and 1.50m, which are classified as low, medium and high, according to the Brazilian standard NBR 13964 (ABNT, 2003).

Among the other parameters, maintained constant, it is highlighted that in the city of São Paulo there are two main furniture layouts, the rectangular and the “L” one, most commonly found in the offices (Andrade, 2005). Therefore a typical “L” working station was modeled, composed by one person, chair, monitor and a computer, in addition to the partition, as showed on Fig. 3. These working stations were placed with occupancy density of 9,5m²/person (Fig. 1).

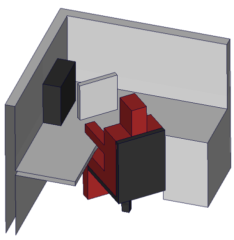


Figure 3. Workstation with high partitions.

2.3 Numerical model

Two commercial softwares were used to generate the meshes: ANSA for the superficial mesh and TGrid for the volume mesh. Fluent was the commercial software chosen as solver. The numerical model is composed by the analyzed building, with five floors and a far field around it, as shown on Fig. 4. Since the geometry is symmetrical, the simulated domain is half the original one, in order to reduce the name of elements and save computational processing time. Also, there is a velocity inlet, shown in blue, a pressure outlet, shown in red, and symmetry boundary conditions on the top, side and symmetry plane.

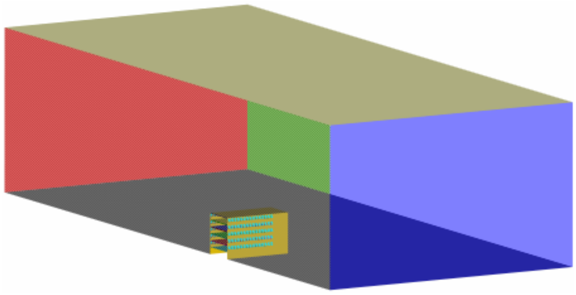


Figure 4. Computational domain.

Four heating generating elements were included over the analyses: personal computers, people, computer monitors and lighting. Heat generating values of the first three of them were obtained in NBR 16401-1 (ABNT, 2008c). Lighting power was estimated taking in account recommendations of energy efficiency standard ASHRAE 90.1 (ASHRAE, 2007b), considering space-by-space method. All heat generation values are detailed in Tab. 1.

Table 1. Heat generation elements used on the numerical analysis.

Element	Heat Generation Rate
Personal computers	55 W
Sitting person	130 W
Computer monitor	70 W
Lighting	12 W/m²

2.4 Equations

The natural ventilation of an environment involves fluid motion and heat exchange. To predict the momentum transfer, it is necessary to choose a turbulence model among available k-ε models, which presents good compromise between accuracy and computational expenses (Zhang et al, 2007). Heat exchange in office environments includes convective and radiative energy transfer (ASHRAE, 2004). Therefore, both phenomena must be modeled.

As presented on ANSYS Fluent (2010a), the first important equation is the continuity equation, described in Eq. (1). The k-ε turbulence model comes from the Reynolds averaged Navier-Stokes equation, Eq. (2), and the Boussinesq hypothesis, Eq. (3).

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x_i}(\rho u_i)=0 \tag{1}$$

$$\frac{\partial}{\partial t}(\rho u_i)+\frac{\partial}{\partial x_j}(\rho u_i u_j)=-\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}-\frac{2}{3}\delta_{ij}\frac{\partial u_l}{\partial x_l}\right)\right]+\frac{\partial}{\partial x_j}\left(-\rho\overline{u'_i u'_j}\right) \tag{2}$$

$$-\rho\overline{u'_i u'_j}=\mu_t\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)-\frac{2}{3}\left(\rho k+\mu_t\frac{\partial u_k}{\partial x_k}\right)\delta_{ij} \tag{3}$$

Where ρ is the fluid density, t is the time, u_i is the velocity on i direction, x_i is the coordinate on i direction, u_j is the velocity on j direction, x_j is the coordinate on j direction, ρ is the fluid density, μ is the dynamic viscosity, δ_{ij} is the identity Tensor, u_l is the velocity on l direction, x_l is the coordinate on l direction, u'_i is the velocity fluctuation on i direction, u'_j is the velocity fluctuation on j direction, μ_t is the turbulent dynamic viscosity, k is the turbulence kinetic energy, u_k is the velocity on k direction and x_k is the coordinate on k direction.

Turbulent viscosity and turbulent kinetic energy can be obtained from the realizable k-ε equations and constraints, presented in Eq. (4), Eq. (5), Eq. (6) and Eq. (7).

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_j}(\rho k u_j)=\frac{\partial}{\partial x_j}\left[\left(\mu\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k+G_b-\rho\varepsilon-Y_M+S_k \tag{4}$$

$$\frac{\partial}{\partial t}(\rho \varepsilon)+\frac{\partial}{\partial x_j}(\rho \varepsilon u_j)=\frac{\partial}{\partial x_j}\left[\left(\mu\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right]+\rho C_1 S\varepsilon-\rho C_2\frac{\varepsilon^2}{k+\sqrt{v\varepsilon}}+C_{1\varepsilon}\frac{\varepsilon}{k}C_{3\varepsilon}G_b+S_\varepsilon \tag{5}$$

$$C_1=max\left[0.43;\frac{\eta}{\eta+5}\right],\eta=\sqrt{2S_{ij}S_{ij}}\frac{k}{\varepsilon} \tag{6}$$

$$C_2=1.9,\sigma_\varepsilon=1.2,\sigma_k=1.0,C_{1\varepsilon}=1.44,C_{3\varepsilon}=tanh\left|\frac{V}{u}\right| \tag{7}$$

Where σ_k is the turbulent Prandtl number for k, G_k is the generation of turbulence kinetic energy due to mean velocity gradients, G_b is the generation of turbulence kinetic energy due to buoyancy, ε is the turbulence kinetic energy rate of dissipation, Y_M is the contribution of fluctuating dilatation in compressible turbulence to the overall dissipation rate, S_k is a user-defined source term, σ_ε is the turbulent Prandtl number for ε, S_{ij} is the mean rate-of-strain Tensor on i and j directions, S_ε is a user-defined source term, v is the kinetic viscosity, V is the component of flow velocity parallel to the gravitational vector and u is the component of flow velocity perpendicular to the gravitational vector.

The energy equation can be found in Eq. (8), and it considers the convective heat transfer presented on the fluid motion. To represent the radiative energy transfer, the radiation model "DO" was adopted, as described in Eq. (9).

$$\frac{\partial}{\partial t}(\rho E)+\frac{\partial}{\partial x_i}[u_i(\rho E+p)]=\frac{\partial}{\partial x_j}\left(k_{eff}\frac{\partial T}{\partial x_j}\right)+S_h \tag{8}$$

$$\nabla\cdot\left(I(\vec{r},\vec{s})\vec{s}\right)+(a+\sigma_S)I(\vec{r},\vec{s})=an^2\frac{\sigma T^4}{\pi}+\frac{\sigma_S}{4\pi}\int_0^{4\pi}I(\vec{r},\vec{s}\,')\Phi(\vec{s},\vec{s}\,')d\Omega' \tag{9}$$

Where E is the total energy, k_{eff} is the sum of thermal conductivity and turbulent thermal conductivity, T is the temperature, S_h is a user-defined source term, I is the radiation intensity, $\vec{r}$ is the position vector, $\vec{s}$ is the direction vector, a is the absorption coefficient, σ_S is the scattering coefficient, n is the refractive index, σ is the Stefan-Boltzmann constant, $\vec{s}\,'$ is the scattering direction vector, Φ is the phase function and Ω' is the solid angle.

2.5 Numerical approach

To make the numerical convergence easier, at the initial iterations it was used the first order discretization of standard k-ε turbulence model, energy equation, DO radiation model and body-force weighted pressure scheme, as recommended by ANSYS Fluent (2010b). After some iterations, these parameters were changed to the realizable k-ε turbulence model and second order discretization of the equations, to ensure better quality of the numerical solution.

The unsteady nature of natural convection introduces the need of changing the default under relaxation coefficients, as suggested by ANSYS Fluent (2010b). Smaller coefficients dump the transient phenomena, making possible the attainment of a steady-state solution with residuals under 10^{-3} for fluid motion and 10^{-6} for energy.

2.6 Mesh independence

To perform mesh independence investigation, two cases were chosen, both of them with maxim-air window geometry. One of them has 1.10m height partitions and the other one with 1.50m.

To analyze the mesh independence, the growth rate of tetrahedrons was changed on both models from 1.9 to 1.6 and later to 1.3, totalizing six simulations. The analyzed variables were the air flow inside the office, the air temperature far from the workstations and an average comfort temperature, defined as the average of calculated air temperatures at points located at 0.10m, 0.60m and 1.10m height near all workstations.

As can be seen on Tab. 2, with the 1.9 growth rate the mean air temperature is higher in the office with 1.50m height partitions, while the airflow is higher in the other office with 1.10m partitions height. These agreed with initial expectations, but the average comfort temperature was higher in the office with smaller partitions. Therefore, it is needed to refine the mesh until coherent results are obtained.

Table 2. Air flow, air temperature and average comfort temperature for two naturally ventilated offices, with different partitions height and mesh tetrahedrons growth rates.

Partitions Height	Analyzed Variable	Tetrahedrons Growth Rate		
		13	1.6	1.9
1.10m	Airflow (kg/s)	10.67	10.63	10.,66
	Air Temperature (K)	300.7	300.8	300.8
	Average Comfort Temperature (K)	301.8	301.7	301.5
1.50m	Air Flow (kg/s)	10.42	10.38	10.33
	Air Temperature (K)	301.4	301.5	301.5
	Average Comfort Temperature (K)	302.0	301.9	301.9

Analyzing the 1.6 growth rate results on Tab. 2, one can see that all results are within the expected results, including the average comfort temperature. The same offices were simulated with 1.3 growth rate, and the results were the same comparing the partitions heights: 0.25kg/s in the airflow, 0.7K in the air temperature and 0.2K in the average comfort temperature. Therefore, there is no gain in refining the mesh, since the results difference remains the same.

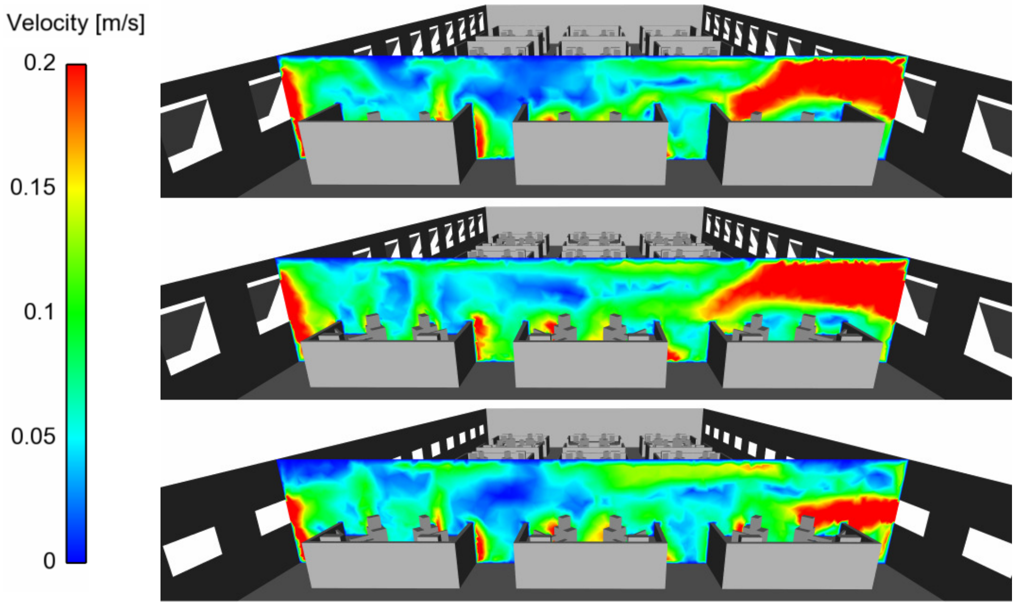
3. RESULTS

For maximal air speed of 2m/s, the partitions height has little influence on the total amount of air entering the ventilated office, as detailed on Tab. 3. However, changing the window geometry, one can see that vertical sliding windows provide less air than the maxim-air, despite the different effective opening areas. According to the CFD analysis, the average reduction of air flow due to the vertical sliding window is 32%.

Table 3. Air inflow of the ventilated office

	Air Mass Flow (kg/s)		
Window Geometry	0.90m partition height	1.10m partition height	1.50m partition height
Maxim-air	10.69	10.63	10.38
Vertical sliding	7.14	7.25	7.12

When lower partitions are used in the office, the airflow distribution is more uniform, as can be seen on Fig. 5. This difference can be seen more easily on the left side of the office, closer to leeward windows. However, changing the window geometry brings more significant differences to the airflow inside the office. Vertical sliding windows provide more intense air velocity over the workstations on the windward side of the office, but less on the higher side of the environment. These lead to a less intense velocity field on the leeward side, as can also be seen on Fig. 5.



a) partitions height: 1.50m window geometry: maxim-air

b) partitions height: 1.10m window geometry: maxim-air

c) partitions height: 1.10m window geometry: vertical sliding

Figure 5. Air speed in naturally ventilated offices with different window geometries and partition heights.

Figure 6 presents airflow streamlines of the same offices from Fig. 5. The phenomena pointed out on vertical planes of the offices are repeated over the entire environment. It is interesting to detach that in office (b) streamlines penetrate further than in office (a), which is related to the different air velocity close to leeward workstations. Also, it can be seen that in office (c) streamlines are more horizontal than in other offices, reducing air penetration inside the environment.

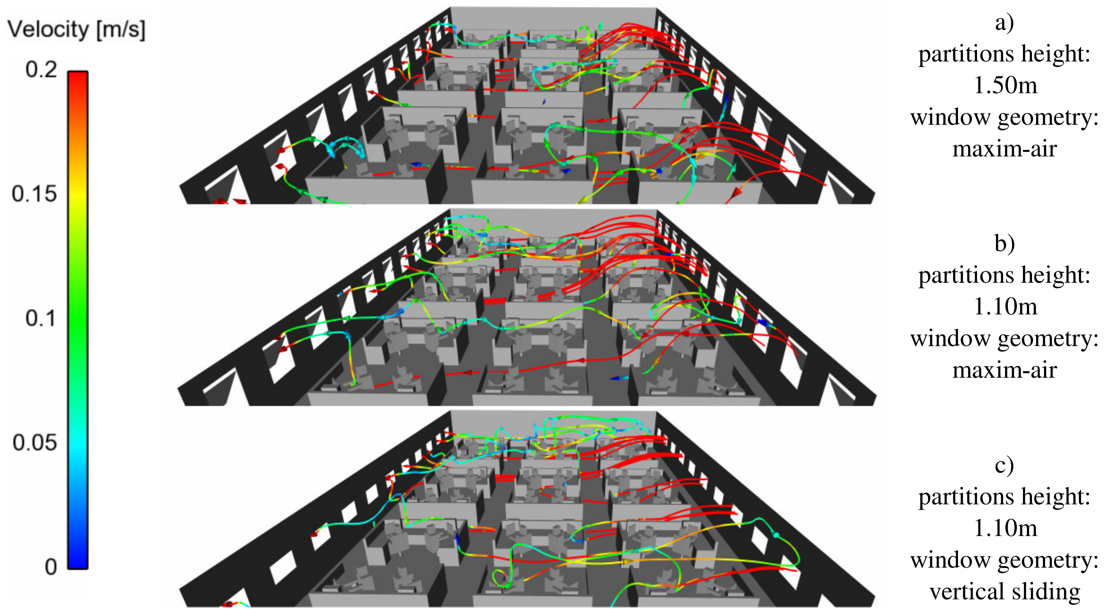


Figure 6. Streamlines across naturally ventilated offices with different window geometries and partition heights.

Regarding the air temperature field, presented on Fig. 7, one can see that in offices (a) and (c) the presence of thermal plumes is more intense. Since these offices present less air speed, natural convection should play a more significant role than in office (b). One consequence is higher air speed close to heat generating elements than the ceiling, as can be seen on Fig. 5 for leeward side of offices (a) and (c).

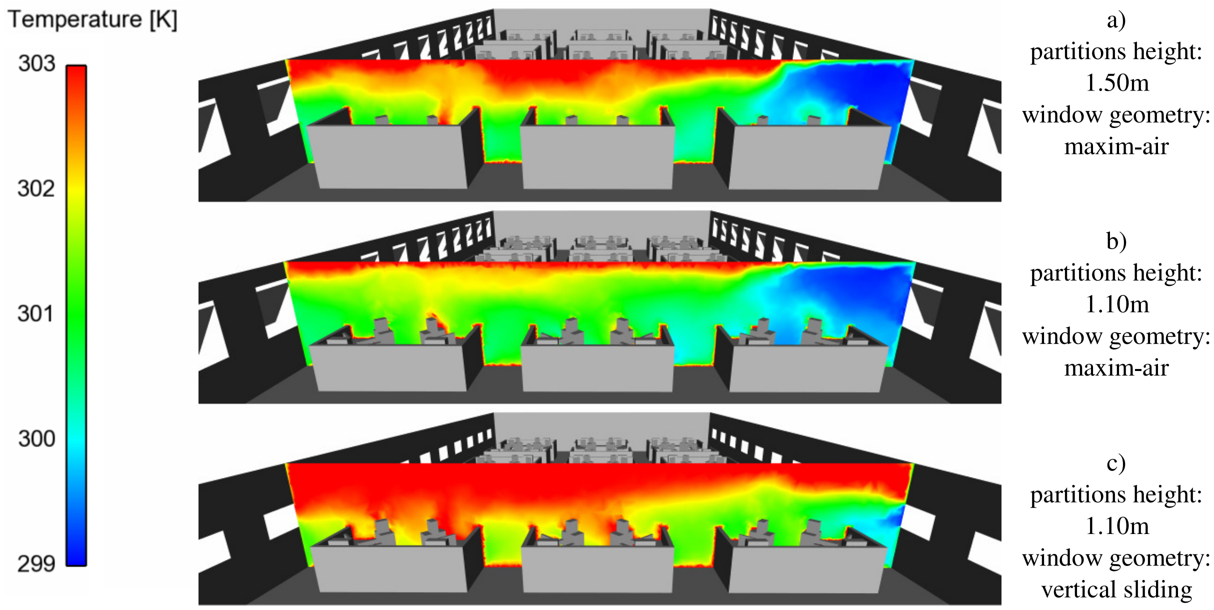


Figure 7. Air temperature in naturally ventilated offices with different window geometries and partition heights.

Figure 8 presents surfaces of constant temperature equal to 300.9K, where the exposed area has temperatures over this value, while the hidden area is cooler. One can see that with vertical sliding windows the higher temperatures can be found on the office, therefore the presence of thermal plumes is expected to be higher as well.

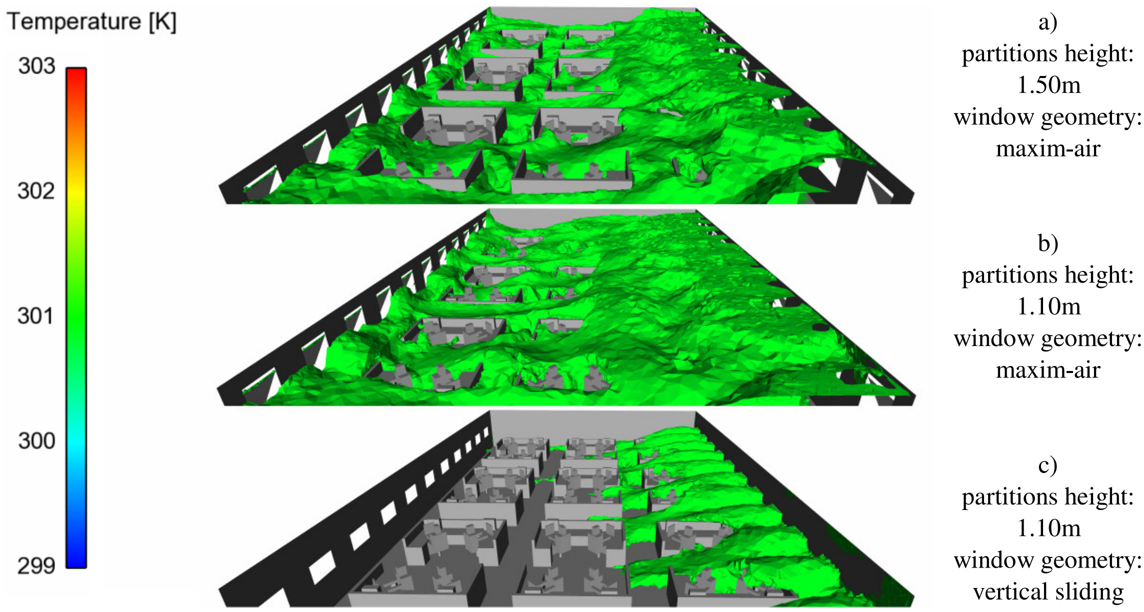


Figure 8. Constant temperature surfaces in naturally ventilated offices with different window geometries and partition heights.

Table 4 presents some quantitative differences for the air temperatures in analyzed offices. Once more the window geometry causes significant differences, as can be seen for both air and average comfort temperatures. However, this time the partitions height causes some quantifiable differences as well, as can be seen for offices with maxim-air windows. These present a temperature difference of almost 1K, which enhances the natural convection air motion, as described before.

Table 4. Air temperature and average comfort temperature for naturally ventilated offices with different partitions height and windows geometry

Window Geometry	Partitions Height (m)	Air Temperature (K)	Average Comfort Temperature (K)
Maxim-air	0.90	300.6	301.6
	1.10	300.8	301.7
	1.50	301.5	301.9
Vertical sliding	0.90	302.2	302.7
	1.10	302.3	302.8
	1.50	302.5	303.2

4. CONCLUSIONS

CFD analysis of the naturally ventilated offices can be an interesting and useful tool, since it provides quantifiable data to compare different windows and furniture configurations. Simulations results help also to describe the velocity and temperature fields in these environments, providing more information to assist engineers and architects to design workspaces with better environmental conditions.

The window geometry plays a significant role in determining the airflow of a naturally ventilated office. Maxim-air windows allow the entrance of more air inside the office, causing higher velocities over the workstations. Also, this window geometry directs the incoming air towards the ceiling, which makes easier to provide fresh air on the leeward workstations. These characteristics cause a more intense velocity field on the environment, enhancing the forced convection and therefore the heat removal from people and computers.

On the other hand, the partitions height plays a less significant role on the office ventilation. When maxim-air windows are used, the incoming air is directed to the ceiling. Therefore, the 1.50m height partition blocks only a small amount of air, making its environmental conditions closer to the 0.90m height partition. More significant differences can be found on the leeward workstations, where forced convection is less intense and the smaller partitions allow the air to flow more easily over the environment.

The partitions height influences more the airflow when vertical sliding windows are used. Since these openings direct the incoming air more horizontally, the 1.50m height partitions block a higher amount of air. This leads to a smaller velocity field near the workstations and reduces the forced convection. As the heat removal is prejudiced, the air temperature near the workstations increases, which causes higher average comfort temperatures showed in Tab. 4.

Having all that in mind, it is reasonable to point out that, in order to enhance the airflow in a naturally ventilated office, the use of maxim-air windows should be preferred over the vertical sliding. Furthermore, partitions should be kept with low height to enhance cooling performance of natural ventilation. However, there is little difference between the 0.90m and the 1.10m height partitions, so other design criteria, like the user privacy, should be taken into consideration when choosing the workstations configuration.

5. REFERENCES

ABNT – Associação Brasileira de Normas Técnicas, 2003. NBR 13964: Móveis para escritório – Divisória tipo painel. ABNT, Rio de Janeiro.

ABNT – Associação Brasileira de Normas Técnicas, 2008a. NBR 16401-3: Instalações de ar-condicionado – Sistemas centrais e unitários: Parte 3: Qualidade do ar interior. ABNT, Rio de Janeiro.

ABNT – Associação Brasileira de Normas Técnicas, 2008b. NBR 16401-2: Instalações de ar-condicionado – Sistemas centrais e unitários: Parte 2: Parâmetros de conforto térmico. ABNT, Rio de Janeiro.

ABNT – Associação Brasileira de Normas Técnicas, 2008c. NBR 16401-1: Instalações de ar-condicionado – Sistemas centrais e unitários: Parte 1: Projetos das instalações. ABNT, Rio de Janeiro.

Alloca, C., Chen, Q. and Glicksman, L. R., 2003, "Design analysis of single-sided natural ventilation". Energy and Buildings, Vol. 35, pp. 785–795.

Andrade, C. M., 2005. Avaliação de Desempenho em Edifícios de Escritórios: o ambiente de trabalho como meio para o bem-estar produtivo. Master thesis, Universidade de São Paulo, São Paulo, SP, Brazil.

ANSYS Fluent., 2010a. ANSYS FLUENT Theory Guide: Version 13.0.Ansys Inc., Canonsburg.

ANSYS Fluent, 2010b. ANSYS FLUENT User's Guide: Version 13.0.Ansys Inc, Canonsburg.

ASHRAE – American Society of Heating, Refrigerating and Air Conditioning Engineers Inc., 2004. ASHRAE Standard 55-2004: Thermal Environmental Conditions for Human Occupancy.ASHRAE Inc., Atlanta.

ASHRAE – American Society of Heating, Refrigerating and Air Conditioning Engineers Inc., 2007a. ASHRAE Standard 62.1-2007: Ventilation for Acceptable Indoor Air Quality.ASHRAE Inc., Atlanta.

ASHRAE – American Society of Heating, Refrigerating and Air Conditioning Engineers Inc., 2007b. ASHRAE Standard 90.1-2007: Energy Standard for Buildings Except Low-Rise Residential Buildings. ASHRAE Inc., Atlanta.

Cheung, J. O. P. and Liu, C. -H., 2011. "CFD simulations of natural ventilation behavior in high-rise buildings in regular and staggered arrangements at various spacings". Energy and Buildings, Vol. 43, pp. 1149–1158.

CIBSE – Chartered Institution of Building Services Engineers, 2005. Natural ventilation in non-domestic buildings: CIBSE Applications Manual AM10. CIBSE, London.

Costa, L. C. N., 2009. Aproveitamento da Ventilação Natural nas Habitações: um estudo de caso na cidade de Aracaju-SE. Master thesis, Universidade de São Paulo, São Paulo, Brazil.

Etheridge, D. and Sandberg, M., 1996. Buildings Ventilation: Theory and Measurement. John Wiley & Sons Ltd., Chichester.

Gratia, E., Bruyère, I. and De Herde, A., 2004. "How to use natural ventilation to cool narrow office buildings". Building and Environment, Vol. 39, pp. 1157–1170.

ISO – International Organization for Standardization, 2005. ISO 7730: Ergonomics of the Thermal Environment – Analytical Determination and Interpretation of Thermal Comfort using Calculation of the PMV and PPD Indices and Local Thermal Criteria. ISO, Geneva.

Kendrick, C., Martin, A. and Booth, W., 1998. Refurbishment of air-conditioned buildings for natural ventilation. BSRIA, Berkshire.

Lipping, W. and Hien, W. N. "The impacts of ventilation strategies and façade on indoor thermal environment for naturally ventilated residential buildings in Singapore". Building and Environment, Vol. 42, pp. 4006–4015.

Marcondes, M. P., 2010. Soluções Projetuais de Fachadas para Edifícios de Escritórios com Ventilação Natural em São Paulo. Ph.D. thesis, Universidade de São Paulo, São Paulo, Brazil.

Prata, A. R., 1998. Uma Ferramenta Computacional de Avaliação da Ventilação Natural em Projetos Arquitetônicos. Master thesis, Universidade Estadual de Campinas, Campinas, Brazil.

Zhang, Z., Zhang, W., Zhai, Z., Chen, Q., 2007, "Evaluation of Various Turbulence Models in Predicting Airflow and Turbulence in Enclosed Environments by CFD: Part 2 – Comparison with Experimental Data from Literature". HVAC&R Research, Vol. 13, pp. 871–886.

6. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.