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Façades and office buildings in São Paulo (Brazil): aiming for thermal comfort and natural ventilation

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Abstract: This work focused on office buildings in the city of São Paulo, Brazil, aiming to identify façades' design solutions which provide internal thermal comfort conditions for at least 80% of the occupied hours during the year without use of air conditioning. Two building models were proposed. Annual dynamic thermal simulation of sixty four scenarios of office buildings with different configurations (building form, layout and orientation) and ventilation conditions (stack effect and wind effect) were carried out with TAS. The operative temperature was adopted as thermal comfort criteria. The relationship between the ventilation rate and the heat gain in the office through the façade was identified for each case study. The results of the thermal performance were tested against ASHRAE 55 (2004) and CEN EN 15251 (2007). The results provided inputs for the design of possible façades' solutions for the cases of office buildings which fulfilled the criterion of 80% of the annual occupied hours in comfort. The study showed: (i) the extent to which the choice of comfort criteria can impact building design and performance; (ii) it is possible to keep efficient natural ventilation and provide adequate thermal comfort conditions for the office building in São Paulo in a wide variety of architectural and ventilation scenarios; (iii) following the proposed design method several combinations of materials and aperture types are possible for the façades of diverse cases, depending on the relationship "heat gains versus ventilation rates".

Keywords: thermal comfort, office building, natural ventilation, façade, tropics

1. INTRODUCTION

Owing to the nature of the occupation and commercial standards, office buildings are characterized by high internal thermal loads and high energy demands. There is concentration of people and equipment, and the architecture of a great number of office buildings currently under design and/or construction worldwide still follows the basic conventional commercial model, with fully glazed sealed façades and no external shading. Such building physical features often result in overheating in the internal spaces due to the incident solar radiation not only in hot climates, but also in warm and even temperate climatic conditions, increasing the dependence on mechanical cooling..

Internal heat gains, external climate, architectural design and acceptable thermal comfort conditions can be pointed out as major parameters influencing the thermal performance and energy efficiency of office buildings.

The eminent global demand for buildings which are more comfortable for their users and energy efficient (UNEP, 2011), highlights passive strategies as design alternatives to be investigated (e.g. thermal mass, natural ventilation, evaporative cooling, etc).

Natural ventilation is considered one of the most efficient design strategies to provide adequate thermal comfort conditions in offices, in a rather energy efficient manner (Bittencourt & Candido, 2005; Etheridge & Ford, 2008; Yao et al., 2009). Beyond the provision of fresh air requirements, natural ventilation can promote passive cooling of buildings in warm climates for significant parts of the year (Givoni, 1994).

As well as to other passive strategies, the potential periods of natural ventilation during the year and its efficiency will depend on the specific aspects of each building (architectural, thermo-physical properties, occupation density and profile), local climate's potential (i.e. when climatic conditions are favourable for thermal comfort), and users' expectations about the internal environmental conditions.

A series of research has been developed to investigate the natural ventilation use in offices as a strategy to reduce building energy consumption (Arnold, 1996; Ghiaus, 2003; Gratia & Herde, 2003; Rijal et al., 2007; Yao et al., 2009).

Regarding the Brazilian context, the design of medium-size to tall office buildings in the city of São Paulo over the past two decades strongly follows the previously introduced conventional commercial building type, with aspects such as deeper floor plates, extensively glazed sealed façades and reliance all year round on artificial air conditioning systems, even though local climatic conditions allow internal spaces to be coupled with the outside for the majority of the year. On this subject, recent research work (Marcondes, 2004; Benedetto, 2007; Figueiredo, 2007) showed the possibility of naturally ventilate office buildings in São Paulo during parts of the year, indicating a potential of application of such strategy for up to 83% of the year (Figueiredo, 2007), depending on building model and conditions of exposure.

An assessment of medium/tall office buildings marketed under the title of 'environmentally responsive' or 'sustainable' (proposed and/or constructed on the last decade in both local and global contexts) indicated that, as a rule, the design solutions and strategies applied refer to the façade as the fundamental element for the overall building environmental and energy performance.

All things considered, the main objective of this research was to identify façade's design solutions for office buildings in the city of São Paulo which provide internal thermal comfort conditions for at least 80% of the occupied hours during the year without use of artificial air conditioning.

2. CLIMATIC CONTEXT

São Paulo (latitude -23º30'; longitude -46º30'; altitude 803m) has "humid subtropical climate" according to ASHRAE (2009) classification.

Analysis of climate data shows that mild air temperatures occur for around 70% of the year, with average values ranging from 15ºC to 33ºC (Fig.1). Relative humidity levels present an annual average of 80%. High levels of solar radiation happen on all orientations throughout the year, including the south façades, as illustrated by Fig.2. Those facts indicate that solar protection is a key strategy for building's environmental performance on such climate, for all orientations all year round, rather than increasing the thermal resistance of the envelope. Additionally, a climatic diagnosis carried out for São Paulo[1] indicated that: (a) the main strategy (and architectural challenge) to provide thermal comfort conditions is building ventilation,

[1] Analysis carried out in Marcondes (2010) with climate data from Benedetto (2006).

which is required for up to 46% of the year; and (b) there is a potential for use of natural ventilation together with other passive strategies, such as thermal mass, for up to 89% of the year.

3. OBJECTIVE

The main objective of this work was to identify façades' design solutions for office buildings in the city of São Paulo which provide internal thermal comfort conditions for at least 80% of the occupied hours during the year without use of air conditioning.

4. BUILDING MODELS

Two building models were proposed as reference of office buildings with thermal and energy performance optimized for local climatic conditions, and to allow for natural ventilation with occupant control: reference models (or analysis' "base case").

The first one presents square open plan with a central service core, a typical formal model of office buildings in São Paulo. Alternatively, the second reference building has a narrower plan with two lateral service cores – a common configuration for European buildings.

Both reference models are mid-size buildings composed of a basement, six office storeys and a roof floor (see Fig. 6). The key criteria for office plan definition was the maximum plan depth (or the maximum distance from any point in the work space to the façade) of 7,5m (CIBSE, 2005), aiming to enhance the efficiency of natural ventilation within the internal space.

Table 1 shows architectural and constructive characteristics of the offices.

It is worth noticing that, regarding occupation, the values adopted in this research, i.e. 14W/m² for people, 8W/m² for artificial lighting and 10W/m² for equipment use, correspond to a "medium" to "high" office heat gain scenario according to European patterns (Marcondes, 2004), although they are rather challenging for the standard current practice of office buildings in the city of São Paulo (Table 2).

5. THERMAL PERFORMANCE: ASSESSMENT PROCEDURES

Thermal performance evaluations of the reference models were carried out with the objective of establishing a relationship between the ventilation rates inside the offices and the heat gains through the façade. Evaluation method includes analytical studies for the prediction of reference ventilation rates for the offices, and annual dynamic thermal simulations of the reference building models.

The scenarios of analysis consider the two reference building models - square and rectangular forms; two office internal layouts: open-plan and cellular; and eight solar orientations (Table 4).

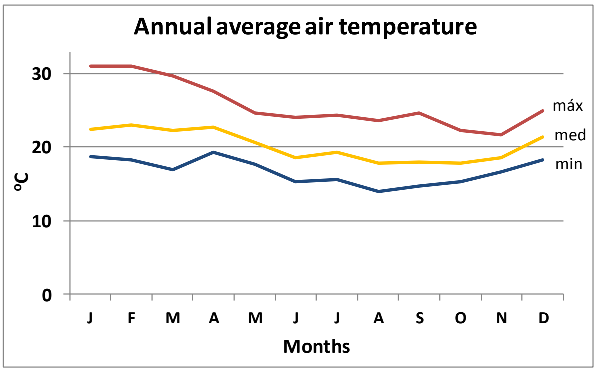


Figure 1. Annual average air temperature data for São Paulo (data from Benedetto, 2006)

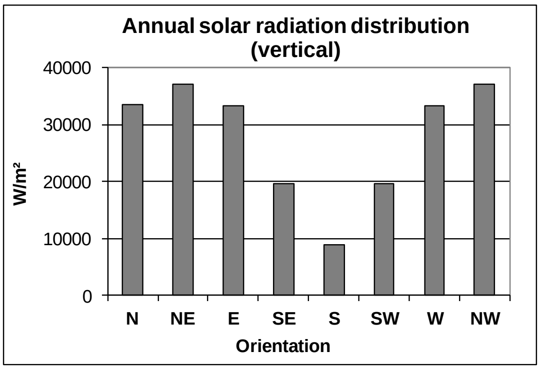


Figure 2. Annual solar radiation distribution by orientation for São Paulo (data from Benedetto, 2006 in Climaticus 4.2)

Table 1. Building model: architectural and constructive characteristics

Building model: architectural and constructive characteristics

office floor area	900m² gross	675m² net	
office internal space	exposed concrete slabs	(CIBSE AM10, 2005; CIBSE AM13, 200)	
	raised floor with carpet		
	free floor to ceiling height	3m (CIBSE AM10, 2005)	
façades	window to wall ratio **(wwr)**	50% (Marcondes, 2004)	
	opaque component	concrete block, light colour finishing	U=2.0 W/m² °C; α=0.3 *
	transparent component	8mm clear laminated glass; no shading	LT=0.87; FS=0.80; SC=0.93**
	window type	'maxim-ar'; 30% efective opening (CIBSE AM10, 2005)	
occupation profile	period	weekdays; 8:00h to	
	density	1 person (140W) to 10m²	
	thermal load	people	14W/m²
		artificial lighting	8W/m²
		equipment	10W/m²

* "U" is the thermal transmission coefficient, in W/m² °C; "α" is the solar radiation absorptance coefficient.
** "LT" is the light transmittance; "FS" or "g value" is the solar heat gain coefficient; "SC" is the shading coefficient.

Scenario	Heat gains in European offices (W/m²) (Marcondes, 2004) "low"	"medium"	"high"	Adopted thermal loads (W/m²)
People	5-8	8-11	11-15	14
Artificial	3-5	6-9	10-14	8
Equipment	0-6	6-12	12-20	10
Total	**6-16**	**18-30**	**30-50**	**32**

Table 2. Occupation parameters of this study vs. heat gains in European offices

5.1. Thermal comfort criteria

Internal operative temperature was adopted as comfort criteria.

The choice for a reference method for the definition of a comfort band included the adaptive comfort models presented by ASHRAE Standard 55 (2004) and CEN Standard EN 15251 (2007). Both models establish ranges of acceptable operative temperatures or comfort temperatures for the internal environment of naturally ventilated buildings, related to external climatic parameters, and are applied to situations in which users can control some variables within the space and thus adapt to internal and external climatic variations, mainly through window opening adjustment and change in clothing.

In the adaptive model of ASHRAE 55 (2004), acceptable comfort bands are determined by Fig. 3, for two categories:

- one for 80% acceptability, for general application; in this case, he allowable maximum difference between the calculated comfort temperature and the actual indoor operative temperature is ±3.5°C; and
- one for 90% acceptability, recommended for cases which require a more rigorous evaluation of comfort conditions; internal operative temperature can be ±2.5°C from this comfort temperature.

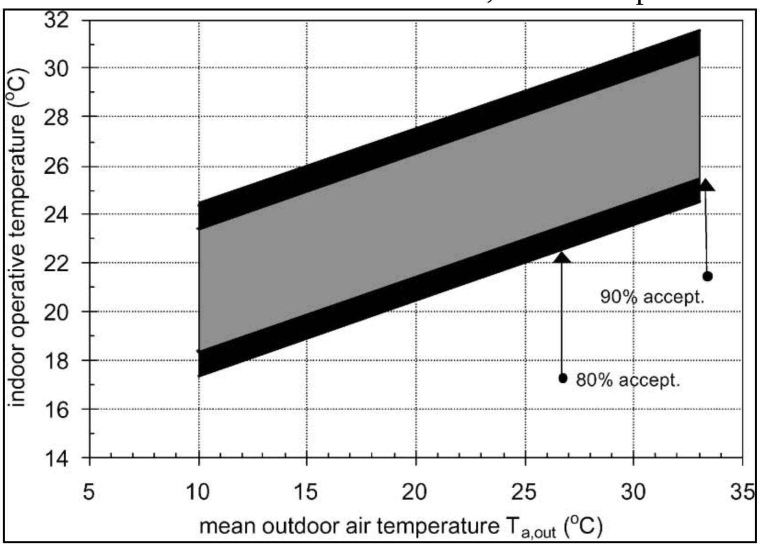


Figure 3. Acceptable operative temperature ranges for naturally conditioned spaces according to ASHRAE 55 (from ASHRAE Standard 55)

The present work considered the temperature range for 80% of satisfied people, as set out for general application, in order to engage occupants in the use of adaptive opportunities.

Alternatively, EN 15251 (2007) establishes ranges of acceptable operative temperatures for four categories, related to users' expectations: Category I, for a high level of expectation and people with special requirements; Category II, for a normal level of expectation; Category III, for a moderate level of expectation; and Category 4, recommended for a limited part of the year only. The allowable maximum difference between this comfort temperature and the internal operative temperature is ±2°C for Category I, ±3 °C for II and ±4 °C for III, as set out in Fig.4.

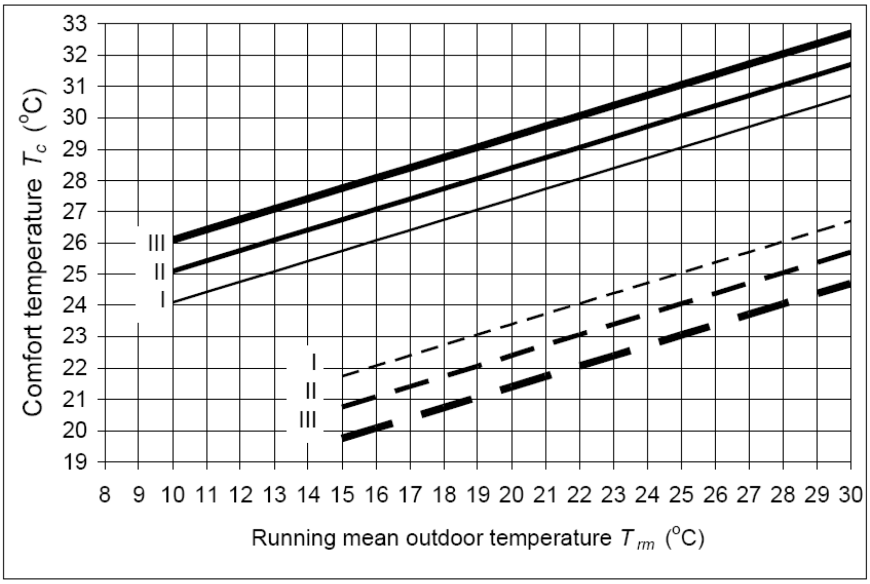


Figure 4. Acceptable indoor operative temperature for naturally ventilated buildings (Nicol & Wilson, 2010 after Standard EN 15251)

Among the categories presented by EN 15251 (2007), Category II was selected for presenting the best correlation with the category chosen from ASHRAE 55 (2004), being for general application and/or a normal level of expectation.

Finally, for both adaptive comfort models assessed, it was defined a limit: the office should be in accordance with the specified comfort conditions for at least 80% of occupied hours during the year.

5.2. Natural ventilation prediction

Natural ventilation studies were developed to calculate a possible ventilation rate for an intermediate office floor of each scenario, to establish the *reference ventilation rate*. Concerning the dynamic condition of the external wind, a reference situation was defined for the prediction of natural ventilation in the offices. Out of the yearly occupied hours during the predominance of south winds (the prevailing wind direction in Sao Paulo for the whole year), one hour was selected to be the representative of the typical climatic conditions, including air temperatures, relative humidity, global radiation and especially wind, both speed and direction. The reference hour is shown at Table 3.

Table 3. Reference hour data for natural ventilation studies (climatic database: São Paulo)

	global solar radiation (W/m²)	difuse solar radiation (W/m²)	dry bulb temperature (°C)	relative humidity (%)	wind speed (m/s)	wind direction (°)
REFERENCE HOUR	**62.1**	**39.0**	**22.0**	**69.0**	**4.5**	**190**

A possible ventilation rate was calculated for the reference hour for each building scenario, considering two ventilation conditions: stack effect and wind effect. The two situations were chosen as an attempt to cover the wide range of possibilities of the external wind condition, including the hours of low speeds, when stack effect could be beneficial (Table 4).

The stack effect ventilation was calculated by the following equations (Frota & Schiffer, 1995):

$$\Phi_{ch} = 0.14 \times A_{ch} \times \sqrt{(H_1 \times \Delta T_1} \qquad m^3/s \qquad (1)$$

$$\Delta T1 = (1\text{-}m) \times \Delta T \qquad (2)$$

where, Φch is the stack effect ventilation rate (m³/s); Ach is the area of the smaller aperture (inlet or outlet, m²); H1 is the distance between the centre of the apertures – air inlet and outlet; m is the inertia coefficient; and ΔT is the difference between internal and external air temperatures.

The wind effect scenario considered south incident wind with 4.5 m/s, accordingly to the reference hour, and was calculated by (BS 5925, 1991):

$$\Phi_V = Cd \times A_o \times V\sqrt{\Delta Cp} \qquad m^3/s \qquad (3)$$

$$\frac{1}{(A_o)^2} = \frac{1}{(Ae)^2} + \frac{1}{(As)^2} \qquad m^2 \qquad (4)$$

where, Φv is the wind effect ventilation rate (m³/s); Cd is the discharge coefficient; V is the external wind velocity on the aperture (m/s); ΔCp is the pressure coefficient difference on the aperture; Ao is the equivalent aperture area for ventilation; and Ae and As are the air inlet and outlet areas, respectively (m²).

For the wind effect condition it was adopted Cd=0,6 (Frota & Schiffer, 1995; Cóstola, 2006), and the calculated pressure coefficients (Cp) are presented by Fig. 5.

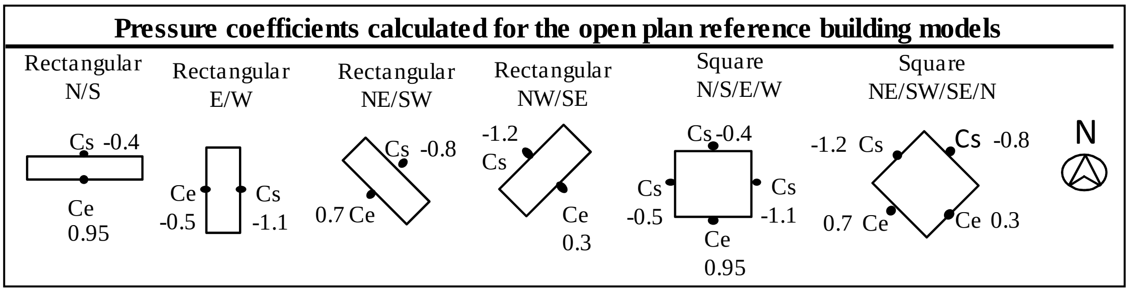


Figure 5. Pressure coefficients for air inlet (Ce) and air outlet (Cs) calculated for the reference building models according to wind direction, with the method proposed by Sharag-Eldin (2007)

Table 4. Scenarios of analysis: architectural parameters and ventilation conditions of the building model

Natural ventilation mode		Stack effect	Wind effect
External exposure		Wind from the surroundings is obstructed by neighbouring buildings	No surrounding obstructions to wind access
Building form		Rectangular Square	
Internal layout		Open plan Cellular plan	
Orientations	Rectangular	North/south, east/west, northwest/southeast, northeast/southwest	
	Square	North/south/east/west, northwest/southeast/northeast/southwest	

5.3. Dynamic thermal simulation

Annual dynamic thermal simulations (TAS 9.1.3) were performed on the reference building models for two building forms, two office layouts, eight orientations and two ventilation conditions, resulting in sixty four scenarios (Fig. 6).

Simulation parameters: During the occupied period, it was considered a fixed internal load of 32W/m² concerning people, equipment and artificial lighting, as already mentioned; and a fixed ventilation rate, previously calculated for each scenario considering the maximum aperture of the windows. During non-occupied hours, a ventilation rate of 4ach was adopted for the offices; it considers some night-time ventilation additionally to minimum infiltration rates' requirements (CIBSE AM13, 2000).

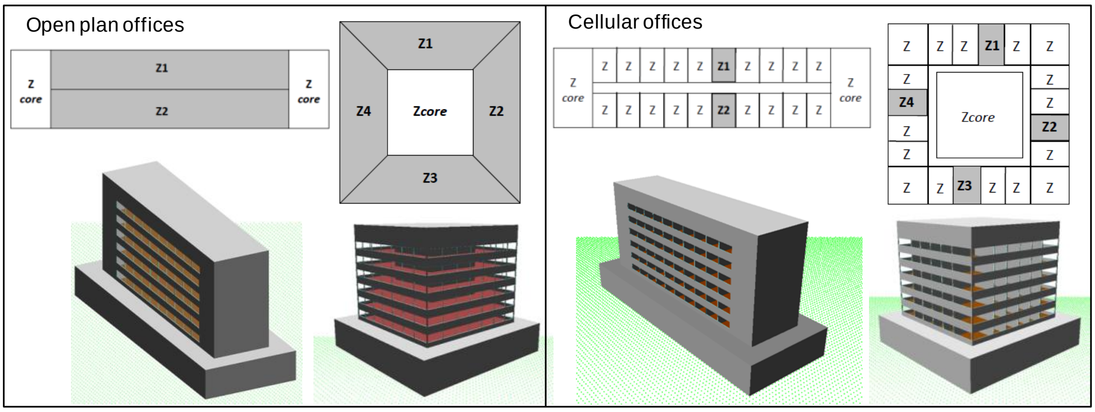


Figure 6. Rectangular and square building models at TAS: plans with zones of analysis and building external views; open plan offices (left) and cellular offices (right).

Based on the simulation results, firstly it was calculated the internal operative temperature, according to the adopted criteria; and the number of occupied hours in "comfort" during the year was evaluated considering both methods presented by ASHRAE 55 and EN 15251. Secondly, among the group of hours in "comfort" it was detected the maximum heat gain in the office due to incident solar radiation, per area of façade, for each scenario.

5.4. Results

The results varied significantly across the range of design scenarios and environmental conditions, especially with building orientation. Similar ventilation rates were obtained for the scenarios under stack effect ventilation, varying from 6.1ach (air changes per hour) to 7.1ach, depending on building form and internal layout. In opposition, for the wind effect condition the results differed greatly, notably depending on wind direction: between 8.7ach and 86.8ach for the building cases with open plan layout – which enabled for cross-ventilation; and between 1.5ach to 11.1ach for the cellular offices. The lowest ventilation rates referred to the east and west oriented offices in the situation where there was wind, because of the south incidence, which resulted in low air velocities reaching the internal spaces.

In general terms, for scenarios with the same orientation, cases with higher ventilation rates (or less exposed area) performed better. The open-plan rectangular form presented results around 10% higher than the open-plan square form. Although the latter presented higher ventilation rates, the solar heat gain through the four exposed façades was approximately 40% higher than the solar gain on the rectangular open-plan office (with two exposed façades).

On the other hand, with reduced ventilation rates – mainly comprising the cases of stack effect ventilation – the influence of the solar heat gains in the internal environment was higher. Thus, a better performance was achieved by the cases with less external exposure: the cellular layout offices, with only one exposed façade, comparatively to the open-plan buildings, both rectangular and square form.

5.4.1. ASHRAE 55 (2004) *versus* EN 15251 (2007)

Concerning the two methods assessed for comfort criteria, the number of analysed scenarios which presented a minimum period of 80% of annual occupied hours in accordance with the acceptable comfort conditions is shown in Table 5, being:

- Twenty three scenarios, according to ASHRAE 55 (2004); and
- Twelve scenarios, according to CEN EN 15251 (2007).

Ventilation condition	Building layout	Scenarios		ANNUAL PERIOD OF COMFORT (%)	
		Building form	Orientation	ASHRAE 55	EN 15251
Stack effect	**Cellular**	Rectangular	S	**83.0**	78.5
		Rectangular	SW	**80.4**	76.2
		Square	S	**81.0**	76.8
		Square	SW	**79.5**	75.4
Wind effect	**Open plan**	**Rectangular**	**N S**	**95.7**	**94.5**
		Rectangular	**NE SW**	**94.4**	**92.3**
		Rectangular	**NO SE**	**89.4**	**86.1**
		Square	**N S E W**	**83.6**	**79.0**
		Square	NE SW NW SE	**82.6**	76.6
	Cellular	Rectangular	N	**79.0**	72.6
		Rectangular	**S**	**89.8**	**87.1**
		Rectangular	SW	**81.0**	76.5
		Square	**S**	**88.4**	**85.7**
		Square	SW	**80.1**	75.9

Table 5. Building scenarios in comfort with ASHRAE 55 (2004) and corresponding results with EN 15251 (2007); scenarios in comfort are highlighted

A reduction on the percentage of annual occupied hours in comfort was verified for all the scenarios with the CEN EN 15251 (2007) method in comparison with the results according to ASHRAE 55 (2004), as it can be observed in Table 6 for twenty three building scenarios. That fact was mainly due to the 1°C difference in the range of the accepted operative temperature between the categories considered for the present work (as explained at item 5.1): the comfort band for 80% of satisfied people from ASHRAE 55 (2004) allowing for ±3.5°C; and the Category II from EN 15251 (2007) allowing for ±3°C, less tolerant.

Based on those results, the adaptive model presented by ASHRAE 55 (2004), which is based on the work of Dear & Brager (1998), demonstrated to be more tolerant for naturally ventilated buildings within the climatic conditions of São Paulo. In this matter, Candido et al. (2010) have verified that data gathered on field experiments carried out at a number of Brazilian cities, followed the same trend predicted by the adaptive model of Dear & Brager (1998), being recommended to be part of a Brazilian Standard for naturally ventilated buildings.

5.4.2. Analysis of results according to ASHRAE 55 (2004)

As previously mentioned, twenty three of the sixty four scenarios analysed achieved the comfort criteria based on the method proposed by ASHRAE 55 (2004) for naturally ventilated buildings (Table 6):

- four cellular offices under stack effect ventilation (rooms with south and southwest orientations from both square and rectangular buildings);
- fourteen open-plan offices with wind (all square and rectangular form buildings, except the rectangular east/west office); and
- five offices with cellular layout and wind effect ventilation (the south and southwest rooms of both square and rectangular buildings, and the north room of the rectangular building).

For all the other cases, the desirable comfort conditions were obtained for more than 50% of the year. Except by the cellular offices oriented towards east and west in the wind effect condition, which presented the worst performance, ranging between 13% and 36% of hours in comfort, mainly as a consequence of the low ventilation rates.

Table 6. Summary of results for the 23 building scenarios in thermal comfort - ref. ASHRAE 55(2004)

Ventilation Condition	Building scenarios: percentage of hours in comfort and reference ventilation rates				
Stack effect cellular offices	S = 83% Φ_{ch} = 7ach	SW = 80% Φ_{ch} = 7ach	S = 81% Φ_{ch} = 7ach	SW = 80% Φ_{ch} = 7ach	
Wind effect cellular offices	S = 90% Φ_v = 11.1ach	SW = 81% Φ_v = 7.2ach	S = 88% Φ_v = 11.1ach	SW = 80% Φ_v = 7.2ach	N = 80% Φ_v = 11.1ach
Wind effect open-plan offices	N/S = 96% Φ_v = 74.3ach	NE/SW = 94% Φ_v = 65.1ach	NW/SE = 89% Φ_v = 45.6ach	N/S/E/W = 84% Φ_v = 86.8ach	NE/SW/NW/SE = 83% Φ_v = 76ach

6. FAÇADES' DESIGN SOLUTIONS

A procedure for the design of façades of office buildings with natural ventilation is proposed based on two variables: a) the reference ventilation rate - calculated for each building scenario; and b) the maximum heat gain in the office through the façade due to incident solar radiation, adequate to the acceptable thermal comfort conditions – extracted from the simulations' results among the hours of "comfort" of each case, i.e., a possible façade solution should allow a maximum solar heat gain in the office equal to the highest solar gain identified from the simulations' results for the comfort occupied hours of each scenario; and should provide a minimum ventilation rate equivalent to the reference ventilation rate calculate for each case (Φ_{ch} or Φ_v). The design of possible façades' solution is developed in two steps:

6.1. Step 1 – definition of opaque and transparent components, and wwr

The choice of opaque and transparent or translucent component(s) is done with the equation of solar radiation heat gain from the calculation method proposed by Frota & Schiffer (1995). According to that method, the heat gain through the façade corresponds to the sum of the heat gains due to solar radiation incidence on all the opaque and transparent surfaces, as follows:

$$\mathbf{Q = (A_{op}*U*\alpha*he^{-1}*Rad)+(Atr*FS*Rad)} \quad \text{W} \quad (5)$$

where, Q is the heat gain through façade (W); A_{op} is the opaque component's area (m²); U is the thermal transmission global coefficient (W/m²ºC), α is the solar radiation absorptance coefficient; he is the thermal conductance coefficient of the component's external surface (W/m²ºC); Rad is the global solar radiation incident on the surface (W/m²); A_{tr} is the transparent component's area (m²); and FS is solar heat gain coefficient of the window.

Different arrangements of components, which will generate different façade's solutions, can be tested by defining the components' thermo-physical properties in Eq. (5): U and α for the opaque component(s); and FS for the transparent component(s) and eventual shading devices. By defining the proportion between opaque and transparent surfaces it is established the window to wall ratio or *wwr*.

6.2. Step 2 – Definition of aperture type, area and position

Knowing the reference ventilation rate for each scenario, by using Eq. (1) e Eq. (3) it is possible to determine the necessary aperture area for building natural ventilation (A_{ch} or A_o, depending on ventilation condition). Subsequently, it is possible to select the aperture type, define area and position on one or more surfaces of an office room.

6.3. Example of façade's solutions

Examples of a possible façade solution are presented for three of the twenty three scenarios of offices analysed in which natural ventilation is possible for at least 80% of the year according to the adaptive model presented by ASHRAE 55 (2004) (Fig.7 and Fig.8). The method proposed by AHRAE 55 (2004) was selected for being more tolerant for this work than the one presented by the CEN EN 15251 (2007), as previously mentioned.

Fig.7 shows the rectangular cellular office building and a possible façade solution for the southwest room (solution 1). With use of external louvers, both horizontal and vertical, the façade could present a wwr of 68% with transparent single glazing, resulting in a solar factor (FS) of 0.1, in order to deal with a maximum heat gain of 161.6W/m²façade. To provide a minimum ventilation rate of 7.0ach under stack effect, sliding horizontal windows (with 45% of effective opening) are placed centrally on the façade, with a total aperture area of 6.8 m².

Fig. 8 presents possible solutions for each one of the façades of the rectangular open plan building oriented towards northeast and southwest (solution 2 and solution 3, respectively). Aiming to guarantee a minimum ventilation rate of 65.1ach on the office environment in the wind effect condition, each one of the façades has 15.8m² of aperture area, provided by two sash windows (top and bottom placed) each. Those windows slide behind the structure, enabling more effective area for natural ventilation (90%). The northeast façade (solution 2) could have a wwr of 50%, with green single glazing (FS=0.6) and concrete block walls (U=2.0W/m²°C, α=0.3) in order to deal with a maximum heat gain of 224.4W/m²façade. Alternatively, the southwest façade (solution 3) could present a wwr of 68%, composed by transparent single glazing with external vertical wooden fins (FS=0.08) and the same wall as the southwest façade of the building, to allow for a maximum heat gain of 152.8W/m²façade.

Figure 7. A possible façade solution for the rectangular cellular office building, southwest oriented, under stack effect ventilation – SOLUTION 1

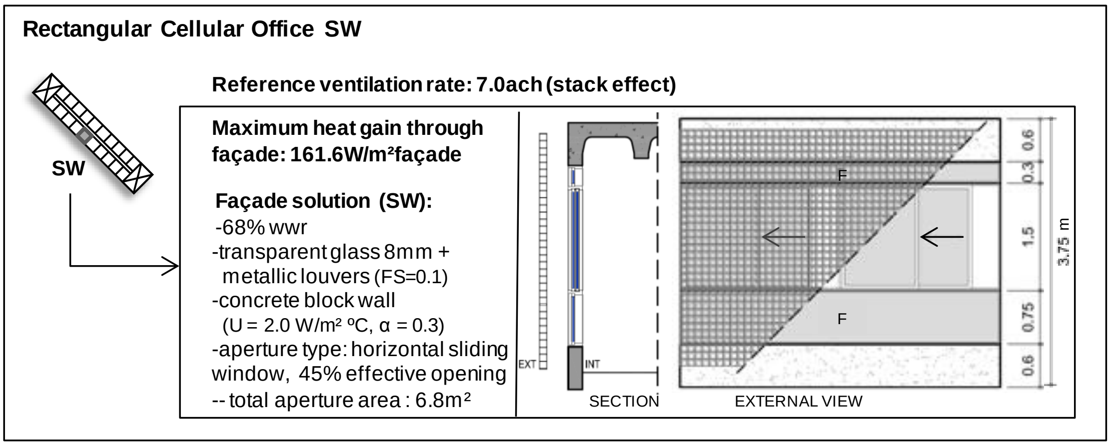
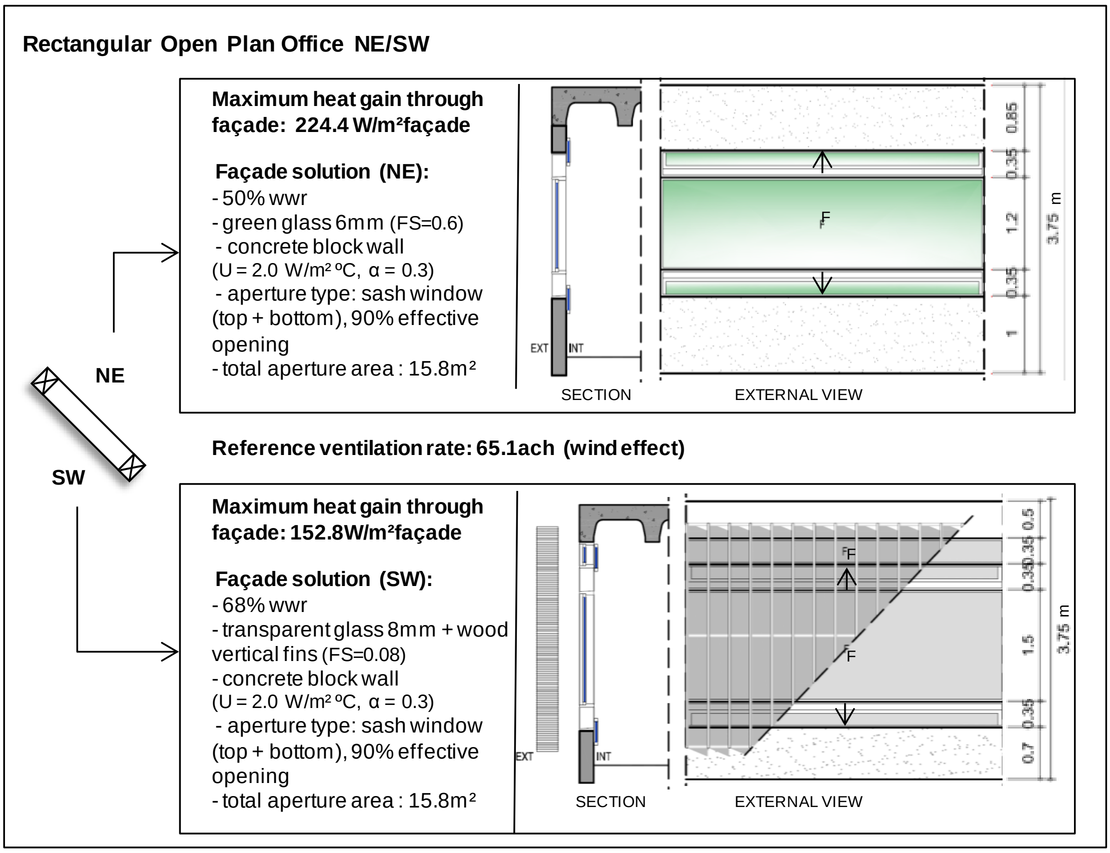


Figure 8. Possible solutions for the northeast and the southwest façades of the rectangular open plan office building, under wind effect ventilation – SOLUTION 2 and SOLUTION 3, respectively



In all three cases the users have control of the windows and therefore can adjust the ventilation conditions of the offices.

Regarding the provision of views of the exterior, it can be more effective to solution 2, which has no obstructions eventhought presenting a lower wwr (50%), than to the other two solutions comprising external shading devices (solutions 1 and 3, with 68% of wwr). For the latter cases, the views of the outside will be filtered by the shading elements, and will depend on the position and distance between those elements.

The external shading devices of solutions 1 and 3 will have the same filtering effect concerning daylight. Those elements will reduce the light transmission to the office space. On the other hand, an adequate design and dimensioning of the external shading elements might be beneficial as it can block direct solar radiation and allow for filtered, diffuse light in the work space. For the façade solution 2, the green glass will also allow for a reduced light transmission in comparison with a transparent glass, due to its thermo-physical properties. In that case, since the direct solar radiation is not completely blocked, occupants might eventually need to use internal blinds, fact which might lead to a poor daylight quality and an increased use of artificial lighting.

Additionally, if the external shading devices of the façades were movable and adjustable, than it would enable users to have even more control of the internal conditions, making adjustments in both ventilation rates and solar protection according to variations in the external climate and/or following the expectations of the occupants in order to feel comfort.

7. CONCLUSION AND FINAL CONSIDERATIONS

The results from the thermal performance evaluation carried out for the office building in São Paulo showed that it is possible to keep efficient natural ventilation in a wide variety of scenarios. It also demonstrated the importance of the choice for thermal comfort criteria, with implications not only for building design, but also for building energy efficiency, as a performance evaluation might indicate the need for use of active strategies for a longer period than the actual building demand.

According to these analytical studies, a possible façade solution for the office building with natural ventilation in São Paulo should attend two principal requirements: to control the solar radiation heat gains – maximum limit; and to allow for adequate ventilation rates in the office space – minimum limit. Thus, emphasis has to be made to the fact that the possible façade's solutions for a given office building with natural ventilation are not replicable, either for other buildings, or for spaces within a building which present different occupancy, use and/or orientation.

The possible cases could be increased if building models were further improved; if internal heat gains were further decreased; if different aperture types, area and position were tested on the façades; and if new thermal comfort parameters were accepted, including the tolerance for higher air temperatures (e.g. above 28ºC) for a few hours during the year. For the vast majority of scenarios which have not met the evaluation criteria, desirable comfort conditions were achieved for more than 50% of the year. That fact indicates that it is worth to investigate the application of mixed-mode strategies for some cases of office buildings in São Paulo.

Finally, it is worth to mention that the use of external shading devices on the façades will be significantly beneficial for thermal comfort as it prevents an increase in the internal superficial temperatures, which might result in discomfort for occupants. Additionally, the impacts of the external shading devices on the ventilation rates and on the daylight quality of the office space should be verified.

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REFERENCES

ASHRAE (2009). Climate Design Data. ASHRAE Handbook. American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta.

Arnold, D (1996). Mixed Mode HVAC. An Alternative Philosophy. ASHRAE Transactions, Vol. 102, n.1, 1996.

ASHRAE Standard 55 (2004). Thermal environmental conditions for human occupancy. ASHRAE, Atlanta.

BCO Guide 2000. British Council for Offices, London, UK.

Benedetto, G. S (2007). Avaliação da aplicação do modo misto na redução da carga térmica em edifícios de escritórios nas cidades de São Paulo e Rio de Janeiro. Dissertação (Mestrado – Área de Concentração: Tecnologia da Arquitetura) – FAUUSP, São Paulo, 2007.

Benedetto, G. S (2006). Organização de banco de dados climáticos. Capítulo para Dissertação de Mestrado. FAUUSP, São Paulo.

Bittencourt, L.; Cândido, C (2005). Introdução à Ventilação Natural. EDUFAL, Maceió, Brasil.

BSI-BS Standard 5925 (1991). Code of Practice for Ventilation. Principles and Designing for Natural Ventilation. British Standard Institution, London, UK.

Candido et al. (2010). Towards a Brazilian standard for naturally ventilated buildings: guidelines for thermal and air movement acceptability. Proceedings of Windsor Conference, Windsor, UK, 9-11 April 2010.

CEN Standard EN 12464 EN 12464-1 (2002) Light and lighting - Lighting of work places - Part 1: Indoor work places. European committee for Standardisation, Bruxelles.

CIBSE Applications Manual AM10 (2005). Natural ventilation in non-domestic buildings. The Chartered Institution of Building Services Engineers, London, UK.

CIBSE Applications Manual AM13 (2000). Mixed mode Ventilation. The Chartered Institution of Building Services Engineers, London, UK.

Climaticus 4.2 software (2005). LABAUT–FAUUSP, Alucci, 2005.

Cóstola, D (2006). Ventilação por Ação dos Ventos: Procedimento para Quantificação. Dissertação (Mestrado) – FAUUSP, São Paulo, 2006.

de Dear, R., Brager, G (1998),Thermal adaptation in the built environment: a literature review. Energy and Buildings, Vol. 27, pp 83-96.

Etheridge, D. W., Ford, B (2008) Natural ventilation of tall buildings – options and limitations. Proceedings of CTBUH 8th World Congress. The Council on Tall Buildings and Urban Habitat, Dubai, 3 – 5 March 2008.

Figueiredo, C (2007). Ventilação Natural em Edifícios de Escritórios na Cidade de São Paulo: Limites e Possibilidades. Dissertação (Mestrado) FAUUSP. São Paulo, 2007.

Frota, A. B.; Schiffer, S. R (1995), Manual de conforto térmico. 2. ed. Editora Nobel, São Paulo.

Ghiaus, C (2003). Free-running building temperature and HVAC climatic suitability. Energy and Buildings, Vol.35, pp. 405-411, 2003.

Givoni, B. (1994). Passive Cooling of Buildings. John Wiley & Sons, New York.

Goncalves, J. C (2003). A sustentabilidade do edifício alto. Uma nova geração de edifícios altos e sua inserção urbana. Tese de doutorado, FAUUSP, São Paulo, 2003.

Gratia, E., Herde A (2003). Design of low-energy office buildings. Energy and Buildings, Volume 35, p. 473-491, 2003.

Marcondes, M. P (2004). Double-Skin façades in high-rise office buildings in São Paulo. A possible environmental efficient solution? Masters Dissertation — Architectural Association Graduate School MA Environment & Energy Studies. London, UK, 2004.

Marcondes, M.P. (2010). Soluções Projetuais de Fachadas para Edifícios de Escritórios com Ventilação Natural em São Paulo. Tese de doutorado, FAUUSP, São Paulo, 2010.

Nicol, F., Wilson, M (2010), An overview of the European Standard EN 15251. Proceedings of Windsor Conference, Windsor, UK, 9-11 April 2010.

Rijal et al. (2007).Using results from field surveys to predict the effect of open windows on thermal comfort and energy use in buildings. Energy and Buildings, Vol. 39, p. 823-836, 2007.

Sharag-Eldin, A (2007). A parametric model for predicting wind-induced pressures on low-rise vertical surfaces in shielded environments. Solar Energy, Vol. 81, p. 52-61, 2007.

TAS. Version 9.1.3 (2009). Milton Keynes, EDSL, Environmental Design Solutions Limited.

UNEP (2011). Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication. United Nations Environmental Programme, www.unep.org/greeneconomy.

Yao et al. (2009). Assessing the natural ventilation cooling potential of office buildings in different climate zones in China. Renewable Energy, Vol. 34, n. 12, p. 2697-2705, 2009.