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NUMERICAL ASSESSMENT OF NATURAL VENTILATION TO PROVIDE COMFORTABLE AND HEALTHY INDOOR ENVIRONMENTS

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Abstract. *Based on the science and industrial efforts to reduce the energy consumption of buildings, this work aims to evaluate different possibilities to minimize the use of HVAC (Heating, Ventilating and Air-Conditioning) systems substituting direct and undirect expansion strategies by natural ventilation when possible. The main idea is to provide information about when natural ventilation can be adopted in a specific climate condition through simulation procedures. The efficient aspects of natural ventilation have been evaluated by using two main criteria, thermal comfort for naturally ventilated spaces and mould growth risk on the indoor surfaces. Both models for thermal comfort and mould growth have been implemented into a whole-energy and building simulation software. In order to test different natural ventilation time intervals, a case study of a typical office building located in Curitiba city has been simulated. A single-sided ventilation model has been adopted to show the potential of natural ventilation in providing thermal comfort to the occupants and reduce mould growth. A parametrical analysis based on the pressure coefficient (C_P) calculation method has also been performed and the influences of the C_P value on thermal comfort and mould growth have also been analyzed. Results have shown that natural ventilation can efficiently be used for almost the whole year in Curitiba, providing more than 63% of time within acceptable comfort levels and reducing mould growth. However, special attention must be taken on the pressure coefficient calculation method, mainly when the mould growth risk is evaluated.*

Keywords: *Natural Ventilation, Thermal Comfort, Building Simulation, Mould Growth.*

1. INTRODUCTION

HVAC (Heating, Ventilating and Air-Conditioning) systems are responsible for a considerable amount of the energy demand in residential and commercial buildings (der Aa and 't Veld, 2004; EPE, 2009). Some works are being developed in order to reduce the energy consumption of HVAC systems while still providing acceptable indoor air conditions to the occupants. Full air conditioned systems were in the past considered as the ultimate choice in terms of thermal comfort, but today a more balanced view, which includes energy saving, is found in many countries. Nowadays, the combination of natural ventilation and air conditioning systems are essential to reduce building energy consumption and, in some cases, natural ventilation can be used as unique strategy to provide those benefits.

In order to contribute to the building energy simulation area and study the influences of natural ventilation on the indoor environment, a previous work presented by Freire *et al.* (2008) has addressed single-sided ventilation models. Those models have been implemented into a whole-building and energy simulation software and validate against wind tunnel and on-site experimental results. Following the same idea, cross ventilation models have been additionally implemented and validated.

The single-sided ventilation model adopted in this work, which has been proposed by Larsen and Heiselberg (2008), has shown better agreement in comparison to both on-site and wind tunnel experimental results, specially when the CPCALC algorithm has been used to calculate the pressure coefficient (Freire *et al.*, 2008a). In this way, the influences of pressure coefficient will also be treated here in order to verify the influences of the pressure coefficient calculation in the occupants' thermal comfort sensation. To evaluate thermal comfort in naturally conditioned buildings, the Adaptive Comfort Standard index (ACS), proposed ASHRAE (2004), has been selected instead of the classical PMV index (Fanger, 1970) that only suits for steady conditions such as those encountered in conditioned spaces.

Additionally, as a sequence of the work presented in (Freire *et al.*, 2008b), the efficiency of single-sided natural ventilation in reducing mould growth at the internal surfaces is also presented. Here, the mould growth risk model proposed by Hukka and Viitanen (1999), capable to estimate the growth rate of mould under different material surface conditions is used and a case study showing the effects of single-sided natural ventilation in both occupants thermal comfort conditions and mould growth on the internal building surfaces, has been addressed.

The next section shows the natural single-sided ventilation model and both pressure coefficient calculation methods that were adopted in this work. Section 3 presents the mould growth risk model. In the sequence, the simulation procedures are presented in Section 4 and the results are shown and discussed in Section 5, and then the conclusions are addressed in Section 6.

presents the ASHRAE thermal comfort index for naturally ventilated spaces and

2. SINGLE-SIDED NATURAL VENTILATION MODEL

The model adopted in this work for the airflow calculation in single-sided openings is the model proposed by Larsen and Heiselberg, (2008). Based on Gids and Phaff's model (de Gids and Phaff, 1982), Larsen (2006) concluded that a more precise design expression found from wind tunnel measurements can be used to predict airflows from single-sided ventilation. From experimental results, Larsen noticed that the wind prevails on the windward side and that the temperature difference stands out on the leeward side of the buildings. As a result, Larsen and Heiselberg (2008) proposed a new model to describe the airflow from single-sided ventilation, which is presented in Equation 1.

$$Q_V = A_o \sqrt{C_1\, C_P\, U_{10}^2 + C_2\, \Delta T\, H_o + C_3\, \frac{\Delta C_{P,opening}\, \Delta T}{U_{10}^2}} \tag{1}$$

where C_P is the pressure coefficient calculated through the curve presented in Fig. 1, U_{10} is the air speed at the reference height of $10\,m$ (m/s), H_o is the opening height (m), the constants C_1, C_2 and C_3 are defined in Tab. 1, and $\Delta C_{P,opening}$, which represents de variations on the pressure coefficient, is calculated according to Equation 2.

Table 1. Constants C_1, C_2 and C_3 (Larsen, 2006).

	C_1	C_2	C_3
Windward	0.0015	0.0009	-0.0005
Leeward	0.0050	0.0009	0.0160
Parallel	0.0010	0.0005	0.0111

$$\Delta C_{P,opening} = 9.1894\, 10^{-9} \beta^3 - 2.626\, 10^{-6} \beta^2 - 0.0002354 \beta + 0.113, \tag{2}$$

where β is the wind incidence angle (^{o}).

The windward, leeward and parallel flows are defined as following:

- Windward, $285^\circ \leq \beta \leq 360^\circ$ or $0^\circ \leq \beta \leq 75^\circ$;
- Leeward, $105^\circ \leq \beta \leq 255^\circ$;
- Parallel, $75^\circ < \beta < 105^\circ$ or $255^\circ < \beta \leq 285^\circ$.

It has also been noted that the values of the constants C_1, C_2 and C_3 depend on the wind direction. This is due to the fact that the flows in the three cases (windward, leeward and parallel) are very different one from each other and therefore also have different weighting of the terms including wind pressure, thermal forces and fluctuating forces. Contrary to what was expected, C_1 does not have the largest weight factor at windward side, but it remains the most dominating factor in this case. In the case where the opening is in the leeward side of the building, the fluctuating term prevails. This is also the case in the parallel wind situations, but here the difference is not as high as in the leeward case.

2.1 Pressure Coefficient Calculation

The C_P coefficient is determined by the shape of the building, the wind direction and the surrounding terrain. In the sequence, two models to calculate the distribution of C_P are presented. The first one considers an unique value for the whole surface whereas the second one calculates the C_P value at any location on the surface.

2.1.1 Mean C_P Equation

According to (ASHRAE, 2005), the distribution of C_P on a low-rise building associated to the variation of the incidence angle can be estimated through the curve presented in Fig. 1. According to (Deru and Burns, 2003), there are several correlations for the wind pressure coefficient derived from wind tunnel experimental data in order of increasing complexity and accuracy, as those proposed in (Walton, 1982; Swami and Chandra, 1988), and by the COMIS group (Feustel and Rayner-Hooson, 1990). These correlations are potentially inaccurate in situations that introduce turbulence to the flow; for example: high terrain roughness or local shielding, irregular shaped buildings (non-rectangular or rectangular with aspect ratios far from a cube) or buildings with overhangs or fins. The model developed by Swami and Chandra (1988) was selected as the best fit for the needs of this work:

$$C_P = C_P(\beta = 0) ln \begin{bmatrix} 1.248 - 0.703 sin\left(\frac{\beta}{2}\right) - 1.175 sin^2\beta + 0.131 sin^3(2\beta G) \\ +0.769 cos\left(\frac{\beta}{2}\right) + 0.07G^2 + 0.717 cos^2\left(\frac{\beta}{2}\right) \end{bmatrix} \tag{3}$$

assuming that:

$$G = \left(\frac{L_1}{L_2}\right) \tag{4}$$

This expression calculates a mean pressure coefficient value of a selected surface on a low-rise building associated to the variation of the incidence angle, in this work it will be called Mean C_P Equation. The surface pressure coefficient normalized to the pressure coefficient at zero incidence angle as a function of the wind incidence angle β within a $[0°, 180°]$ domain, where values higher than $180°$ are obtained by symmetry, and the natural logarithm of the side ratio (ratio of the lengths of adjacent walls L_1 and L_2 (in m). For vertical walls, Swami and Chandra (1988) recommended using a value of 0.6 for the pressure coefficient at zero incidence. Note that the values obtained by Equation 3 lie in Fig. 1 grey area.

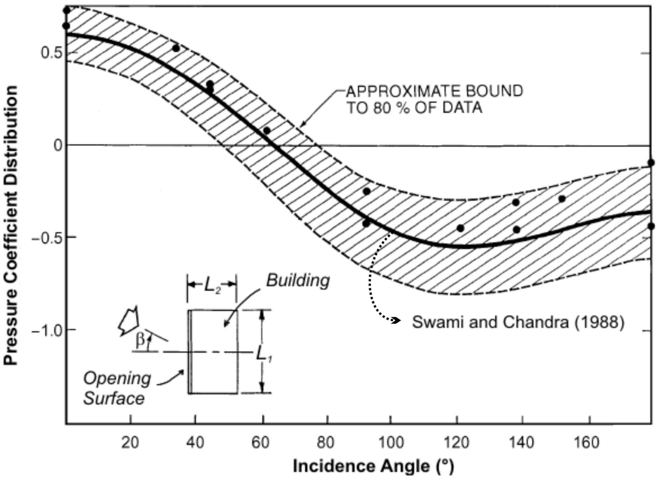

Figure 1. Variation of surface-averaged wall pressure coefficients for low-rise buildings (ASHRAE, 2005a).

2.1.2 CPCALC Model

As the main algorithm of CPCALC+ (software for calculating wind pressure coefficients on the envelope of a building which has been used for airflow modeling), the idea of the CPCALC algorithm was initiated within the European Research Programme PASCOOL (Passive Cooling of Buildings) of the Commission of the European Communities, Directorate General for Energy (Grosso, 1993; Grosso *et al.*, 1994). In 1992 it was developed at the Lawrence Berkeley Laboratory (Feustel and Rayner-Hooson, 1990; Grosso, 1992) within the COMIS workshop on infiltration and ventilation, and being upgraded within the IEA-ANNEX 23 on multizone airflow modeling (IEA, 1996).

CPCALC and CPCALC+ were developed in order to fulfill the requirements of multizone airflow models which need a detailed evaluation of the wind pressure distribution around buildings. Scientists and professionals using this program, and who do not have the possibility to test a scale model of their building in a wind tunnel, do not need to extrapolate C_P data from tables usually yielding wall-averaged C_P values (Liddament, 1986).

The CPCALC model uses the following input variables: β is the wind incidence angle (°), α_R is the wind speed profile (Counihan, 1975), sbh is the surround building height (m), pad is the plan area density ($\%$), the building height (m), the wall azimuth (°) and the coordinates x and y of the middle of the opening related to the origin of the building (m). Finally, L_1 and L_2 represent the frontal and side aspect ratios of the building (m).

Based on these input data, the CPCALC algorithm is able to calculate the pressure coefficient value at any point on building's surface, in this case, at the center of the opening. More information about the CPCALC algorithm can be found in (Grosso, 1993; Grosso *et al.*, 1994).

3. MOULD GROWTH RISK

Since PowerDomus models are able to calculate heat and moisture transfer through porous materials, models that involves wall surface temperature and humidity could be implemented into the software. The aim of this section is to present a mathematical model of mould growth risk that has been implemented into PowerDomus in the frame of the present work.

Over the past decades, mould and mildew growth has been attracting attention of academic and industrial researches, and consequentially greatly increased their understanding specially related to the associated potential health risks. Better understanding about this fungus can help with the removal of this micro organism and, thus, reducing health risk to humans and building structures deterioration.

Mould needs three factors to be able to grow: a food source, moisture, and a certain temperature range. If these three conditions are present, mould will be able to germinate and grow rather quickly. A common believe is that molds need physical water to be able to grow, but that is not the case. Mould need relative humidity be between 65% and 99% at the growing surface. Keeping the relative humidity below 50% will deter mould growth. Based on these factors, Hukka and Viitanen (1999) proposed a model for the growth rate of mould under different material surface conditions.

The scale applied to the present mathematical model comes from an existing standard based on the visual appearance of the surface under study. Some refinements have been made by Hukka and Viitanen and, as a result, the mould growth index (MGR) assumes the values presented in Tab. 2.

Table 2. Mould growth risk index description.

MGR	Growth
0	No growth
1	Some growth detected only with microscopy
2	Moderate growth detected with microscopy (coverage more than 10%)
3	Some growth detected visually
4	Visually detected coverage more than 10%
5	Visually detected coverage more than 50%
6	Visually detected coverage 100%

As a basis of their model, they have presented a regression equation for the response time t_m (time - in weeks - needed for the initial of mould growth at constant surface temperature and humidity):

$$t_m = e^{-0.68\, ln(T_{surf}) - 13.9\, ln(\phi_{surf}) + 0.14\, W_{mat} - 0.33\, SQ + 66.02}, \tag{5}$$

where T_{surf} is the surface temperature ($^\circ C$), ϕ_{surf} is the surface relative humidity ($\%$), W_{mat} is the material constant (adopted here as 0.5) and SQ is the surface quality (adopted here as 0.5). According to Hukka and Viitanen (1999), both, material constant and surface quality index, have been experimentally obtained for resawn and original kiln-dried wood material. In this way, considering the necessity of experimental results for the obtention of different materials constants, the 0.5 value has been adopted.

As the mould index MGR is supposed to increase linearly in time (when time is measured in days), a differential interpretation of Equation 5 can be performed (see Equation 6). This extends the applicability of Equation 5 to transient conditions such that the relative humidity is constantly above the critical value defined by Equation 7 and the temperature lies between 0 and $50^\circ C$.

$$\frac{dMGR}{dt} = \frac{1}{7\, e^{-0.68\, ln(T_{surf}) - 13.9\, ln(\phi_{surf}) + 0.14\, W_{mat} - 0.33\, SQ + 66.02}}, \qquad MGR < 1, \tag{6}$$

$$\phi_{crit} = \begin{cases} -0.00267\, T_{surf}^3 + 0.160\, T_{surf}^2 - 3.13\, T_{surf} + 100.0 & \text{when } T_{surf} \leq 20 \\ 80\% & \text{when } T_{surf} \geq 20 \end{cases} . \tag{7}$$

When interpreting the results of the model, all values of MGR below 1 indicate no growth. If growth proceeds above the initial stage ($MGR = 1$), Equation 6 is no longer valid. In this way, another regression model describing the response time (in weeks) needed for the first visual appearance of mould growth ($MGR = 3$) should be used (see Equation 8):

$$t_v = e^{-0.74\, ln(T_{surf}) - 12.72\, ln(\phi_{surf}) + 0.06\, W + 61.50}. \tag{8}$$

If mould growth index is assumed to be between $MGR = 1$ and $MGR = 6$ on a constant rate in constant conditions, Equations 5 and 8 can be combined to give the growth rate on that range (Hukka and Viitanen, 1999). The result of this combination is a correction coefficient presented below.

$$k_1 = \begin{cases} 1 & \text{when MGR} < 1 \\ \dfrac{2}{\dfrac{t_v}{t_m} - 1} & \text{when MGR} > 1 \end{cases} . \tag{9}$$

Taking into account the upper limit for mould growth defined by Equation 10, another correction coefficient may also be used in order to define the mould growth in fluctuating conditions. This coefficient is presented in Equation 11.

$$MGR_{sup} = 1 + 7\frac{\phi_{crit} - \phi_{surf}}{\phi_{crit} - 100} - 2\left(\frac{\phi_{crit} - \phi}{\phi_{crit} - 100}\right)^2 \tag{10}$$

$$k_2 = 1 - e^{2.3(MGR - MGR_{sup})} \tag{11}$$

Finally the complete model for mould growth in favorable conditions consists of:

$$\frac{dMGR}{dt} = \frac{1}{7\, e^{-0.68\, ln(T_{surf}) - 13.9\, ln(\phi_{surf}) + 0.14\, W - 0.33\, SQ + 66.02}} k_1 k_2 . \tag{12}$$

$MGR = 0$ at initial time has been adopted in the implemented algorithm.

According to Hukka and Viitanen (1999), instead of remaining on a constant level, the activity of mould can be regarded as decreasing during dry periods and a finite delay in growth can be clearly observed after the dry period. This delay does exist as soon as after 6 hours in dry conditions, but extending the dry period to 24 hours does not seem significantly affect it, if growth will initiate at all. After that, the delay occurs again. Following these relations, a mathematical description of the delay can be written by using the elapsed time from the beginning of the dry period $(t - t_1)$ such as:

$$\frac{dMGR}{dt} = \begin{cases} -0.032 & \text{when } t - t_1 \leq 6\,\text{h} \\ 0 & \text{when } 6\,\text{h} \leq t - t_1 \leq 24\,\text{h} \\ -0.016 & \text{when } t - t_1 > 24\,\text{h} \end{cases} \tag{13}$$

4. SIMULATION PROCEDURES

In order to verify the differences in terms of thermal comfort and mould growth by using distinct natural ventilation periods, this section describes the building structure and the adopted simulation parameters.

4.1 Building Description

The building envelope is a two-storey office building divided into two zones. Each zone has $8.0 \times 8.0 \times 3.0$ meters of length, width and height, respectively. The walls are divided into three layers of mortar ($2\ cm$), brick ($15\ cm$) and mortar ($2\,cm$) with external and internal permeances of $9e^{-10}\ kg/(Pa\, m^2\, s)$ and $2e^{-10}\ kg/(Pa\, m^2\, s)$. The hygrothermal properties of each material are presented in Tab. 3.

Two $1.5\ m \times 1.0\ m$ double-glazed windows facing North, with unitary solar heat gain coefficient (at normal incidence), no internal shading device and a global heat transfer coefficient of $3 W/m^2 K$ have been distributed on the building façades. Additionally, a $2.10\,m \times 0.80\,m$ door is added to the building as shown in Fig. 2. No ground contact has been considered, *i.e.*, the building has been placed in the air to avoid simplifications on the heat and moisture transfer via the ground.

Table 3. Materials physical characteristics.

Material	ρ	λ	c_P	ε
Brick	0.749	1900	920	0.29
Mortar	0.720	2050	932	0.18

where λ is the thermal conductivity ($W/m^2\ K$); ρ the density (kg/m^3), ε is the porosity (-) and c_P the specific heat ($J/kg\ K$). Figure 2 shows the building geometric characteristics into the 3-D PowerDomus software interface.

Internal thermal gains from people, lighting and equipment from $8\ am$ to $6\ pm$ have been taken into account. During the occupation time (from $8\ am$ to $6\,pm$), an individual vapor dissipation of $180\ g$ of water at $37°C$ has been considered. This vapor capacity corresponds to the moisture generated by human beings when office activities are considered (IEA, 1991). The main idea is to stipulate that there is always someone in the ground floor during the occupation time.

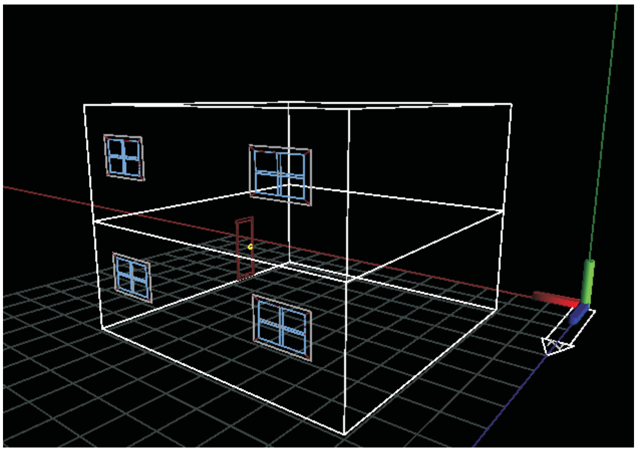

Figure 2. Two-storey office building geometric characteristics (Mendes *et al.*, 2003).

4.2 Simulations and Reports

The Test Reference Year (TRY) of the city of Curitiba, South of Brazil (latitude: -25.52^o; longitude: -49.17^o; GMT: $-3\,h$; altitude: $934\,m$) has been used for one year simulation period. One year pre-simulation period has been adopted to avoid initial conditions effects.

Simulations have been performed using a 20-minute time step and changing two main parameters: *i*) the time that natural ventilation is used considering just one opening (single-sided ventilatio); *ii*) the pressure coefficient (C_P) calculation method; Results are expressed in terms of: thermal comfort and mould growth at the internal ceiling surface, for the ground level (Zone 1). The ground level has been evaluated due to results of previous tests, those results have shown high mould growth potential at the internal ceiling surface, which is protected from the sun heat by the first floor structure. According to these parameters, the following simulations have been performed: ***i)*** openings closed; ***ii)***Natural ventilation configured for one opening from $8\,am$ to $9\,am$; ***iii)*** Natural ventilation configured for one opening from $8\,am$ to $10\,am$; ***iv)*** Natural ventilation configured for one opening from $8\,am$ to $11\,am$; and ***v)*** Natural ventilation configured for one opening from $8\,am$ to $6\,pm$.

5. RESULTS

This section presents the simulation results using the mathematical models for natural single-sided ventilation integrated to a hygrothermal building model. The selected simulation parameters were described in simulation procedure section.

5.1 Mould Growth Risk Analysis

The mould growth risk index have been analyzed for both natural ventilation and air-conditioning cases. The main idea is to assess the potential usage of natural ventilation to avoid the ideal conditions of mould spores growth.

Figure 3 presents the daily mean relative humidity of the internal ceiling surface for the whole year simulation period. As presented in Section 4, the critical value for relative humidity (φ_{crit}) is the main parameter for mould fungi development. As described before, even for temperatures under $20°C$ critical values of indoor air relative humidity can potentially affect the indoor surfaces and, as consequence, proportionate mould growth.

As noticed in Fig. 3, the effect of natural ventilation for the same time interval of air-conditioning system is similar and the roof surface relative humidity has been reduced. However, natural ventilation avoid energy consumption of air-conditioning equipment and improves the indoor air quality if outdoor air is cleaner than the indoor. When the air-conditioning system has been considered, an annual energy consumption of $28,885\,kW$ has been noticed by adding the energy used by pumps, chiller and fan coil.

Figure 4 presents the mould growth on the indoor roof surface when neither natural ventilation nor air-conditioning system is considered during the whole year period. Mould spores found favorable growing conditions when the heat and moisture generated by people and equipment inside the building are not dissipated.

Figures 5 to 7 describe the mould growth index for one year simulation period when the window open intervals are defined as 1, 2 and 3 hours.

Another simulation to evaluate the mould growth potential when the window is open during the occupation time (from $8am$ to $6pm$) has been performed. In this case, no mould growth has been noticed for both pressure coefficient calculation

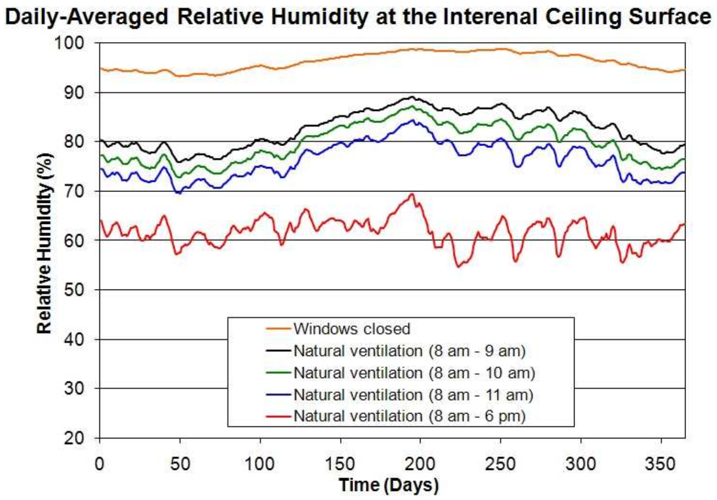

Figure 3. Daily mean relative humidity for the indoor roof surface.

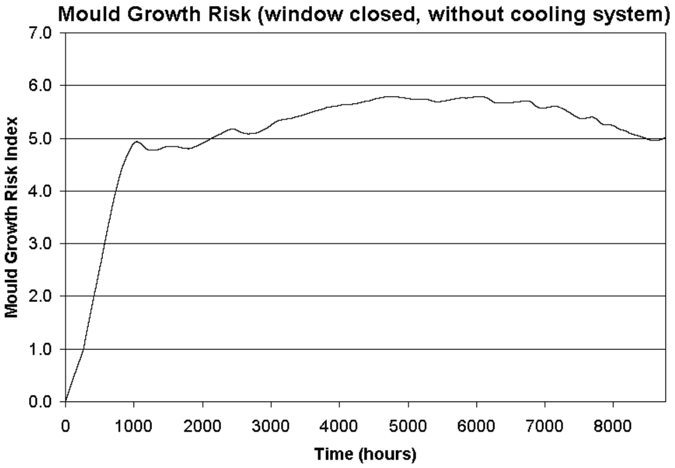

Figure 4. Mould growth risk for one year simulation.

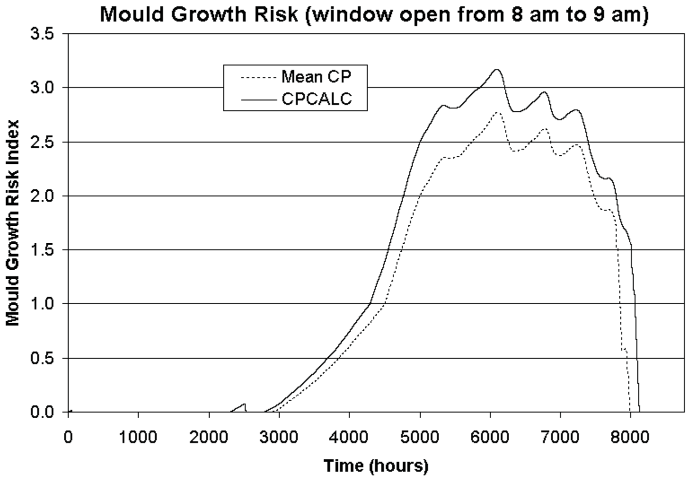

Figure 5. Mould growth risk for one year simulation (window open from 8 am to 9 am).

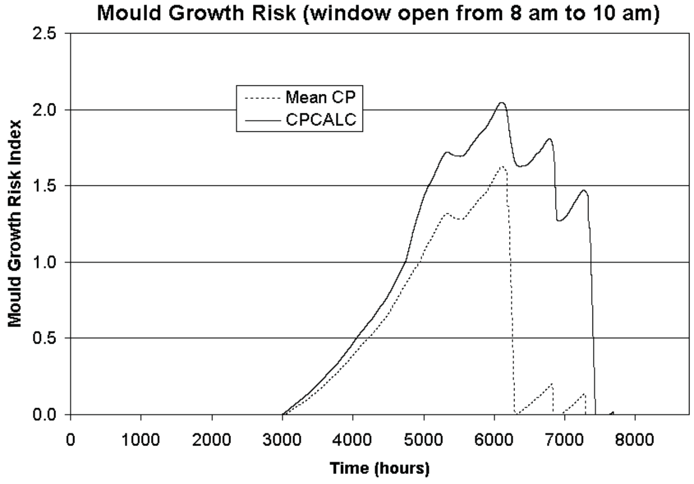

Figure 6. Mould growth risk for one year simulation (window open from $8\ am$ to $10\ am$).

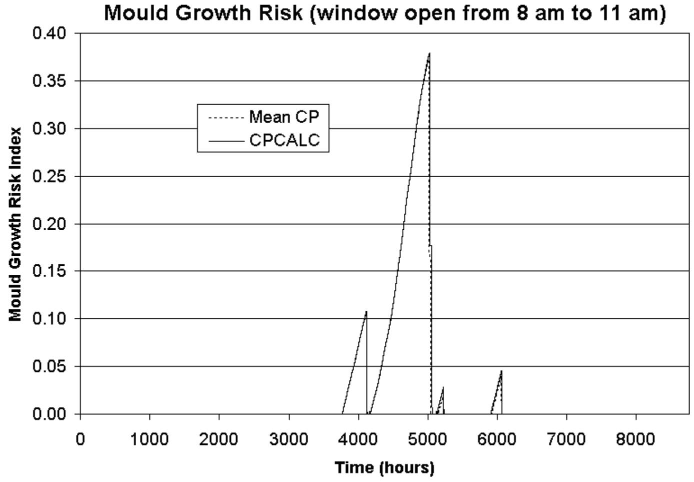

Figure 7. Mould growth risk for one year simulation (window open from $8\ am$ to $11\ am$).

methods. In Fig. 5, it can be noticed that the winter period is responsible for the mould growth in the roof surface. In this case, minimum differences on the airflow rate can affect the mould growth were microscopically (Mean C_P) and visually (CPCALC) detected.

For a two-hour natural ventilation use period, a more significant difference can be seen (Fig. 6). No growth from the CPCALC method has been verified, while some growth has been microscopically detected when the Mean CP calculation method is used. These results report a 45-day period where mould fungi affect the indoor air quality, while for the Mean C_P calculation method there is practically no growth.

Finally, in cases that opening window time is 3 hours or more, results are almost equal when the pressure coefficient models are evaluated (see Fig. 7). In this way, it confirms that for a more precise analysis when moisture transport is considered to evaluate natural ventilation and indoor air quality, it is necessary to use a more precise model to calculate the airflow rate through openings.

5.2 Thermal Comfort Analysis

Besides mould fungi, thermal comfort is an important parameter that must be considered as building design criteria. As presented in the last section, the use of natural ventilation can avoid mould growth when the weather conditions are favorable. In the same way as mould growth risk, thermal comfort is equally important because is strongly related to occupants' healthy satisfaction and productivity.

This section treats the problem of thermal comfort evaluating the effects of natural ventilation in the occupants' thermal comfort. Simulations with opening window time of 1, 2, 3 and 10 hours have not shown significant variations on thermal comfort index when the two pressure coefficient calculation methods are compared.

Table 4 shows the percentage of time in different comfort zones (80% and 90%) under acceptable thermal comfort

Table 4. Percentage of time within the comfort zone for both pressure coefficient calculation methods.

	Percentage of Time within the Comfort Zone (%)			
Open Window	CPCALC		Mean C_P	
Interval	80% Zone	90% Zone	80% Zone	90% Zone
$8\,am - 9\,am$	63.31	47.20	63.27	47.19
$8\,am - 10\,am$	63.47	47.49	63.41	47.51
$8\,am - 11\,am$	63.62	47.59	63.52	47.55
$8\,am - 6\,pm$	67.65	49.01	67.57	48.97

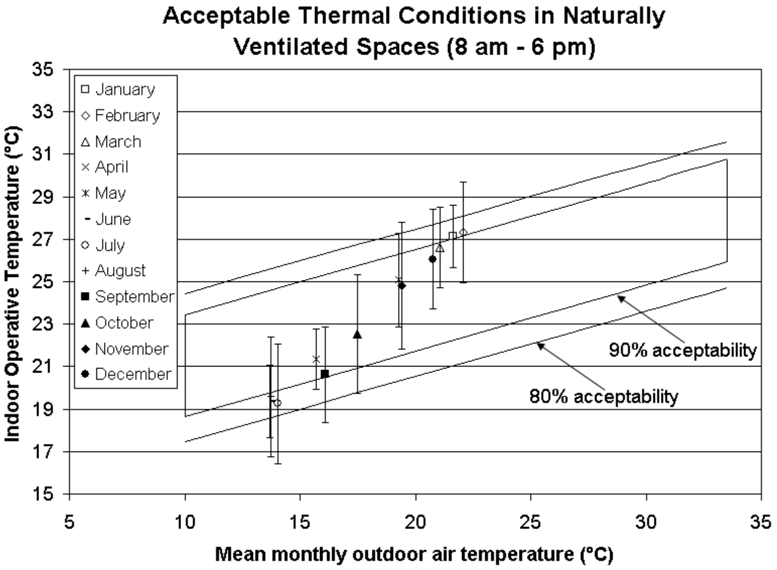

Figure 8. Comfort zone using natural ventilation from $8\,am$ to $6\,pm$.

conditions. As seen in this case, the 10-hour of natural ventilation test period has presented the best results when thermal comfort is evaluated. In this case, differences no higher than 0.08% between CPCALC and Mean C_P algorithms have been noticed. Based on these small differences, Fig. 8 shows the distribution of a mean monthly operative temperature in the ACS comfort zone for the CPCALC pressure coefficient calculation method. No significant differences appear when this graphical visualization is applied to the Mean C_P strategy.

Comparing the results presented in Tab. 4 and Fig. 8, it is noticed that for a long period of time occupants of the building are under acceptable thermal comfort levels. When the results for 1, 2 and 3 hours of window opening time are included into the comparative analysis, it can be concluded that occupants in these cases the indoor air will fell slightly warmer than in the 10-hour case, but with no significant changes on the percentage of time within the comfort zone boundaries.

6. CONCLUSIONS

The present work aimed at evaluating an alternative to energy-consuming air-conditioning systems, *i.e.*, the use of natural ventilation to provide healthy and comfortable conditions to building users. For the studied case of a building located in Curitiba (South of Brazil), it can be noticed that in both thermal comfort and mould growth analysis cases, natural ventilation can be used to optimize thermal comfort conditions for the occupants.

Some evaluations about the influences of the pressure coefficient calculation method on the mould growth risk have also been presented. According to the results, slight variations on the pressure coefficient value may provide significant changes in the mould growth profile and, in these cases, a more elaborated pressure coefficient calculation method should be used.

7. ACKNOWLEDGEMENTS

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9. Responsibility notice

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