ATMOSPHERIC TURBULENCE INFLUENCE ON NATURAL VENTILATION AIR CHANGE RATES

Saraiva, Jorge G. ; Marques da Silva, Fernando
LNEC - NDA, Av. do Brasil 101, 1799 Lisboa Codex, Portugal
Tel : 351-1-8482131 ; Fx : 351-1-8463457 ; e-mail : jsaraiva@lnec.pt; fms@lnec.pt

Keywords : Ventilation; Wind velocity; Turbulence

ABSTRACT

In order to estimate air change rates (ACH) on Natural Ventilation (NV) processes a number of factors should be known as general and openings dimensions, pressure distribution over the facades, internal heat sources (or sinks) and head losses. The atmospheric boundary layer (ABL) characteristics change with the terrain roughness and affect the pressure distribution. Construction features determine infiltration rates, flow regimes through openings and its head losses so affecting the internal airflow. The present paper concentrates on one of the external factors affecting air change rates – turbulence – and it's inclusion on VENTIL, an integral model for NV estimates.

As a result an increased knowledge of NV capabilities is obtained. Some results will be presented as an application to an industrial building under different ABL.

INTRODUCTION

In order to evaluate the air change rates on a NV process a number of factors should be previously known. Concerning the building geometry the planform areas of each internal space, the general dimensions of the building as well as those of the openings and relevant heights of any air passage. From the description of the flow field boundary layer one should know what wind velocity and direction to consider at any height from ground. The flow-building interaction being characterised by pressure coefficients on external openings and head loss coefficients for both internal and external communications. The existence of internal heat sources (or sinks) should be considered as well, together with the thermal characteristics of the walls, air temperature and atmospheric pressure.

Among those factors pressure coefficients (Cp) may be the ones more difficult to be assessed. The information is available for the most common and simple shapes but almost any other situation must go through wind tunnel testing over physical models. Those coefficients are also dependent on the wind velocity reference height, meaning a dependence on the ABL wind velocity profile determined by the surrounding roughness and orography, and highly dependent on the wind direction.

The consideration of an ABL lead to consider a turbulent flow process and to the direct influence of turbulence on the ventilation process. The turbulent flow simpler models consider the instantaneous wind velocity represented by the sum of the mean value and a fluctuation - $U = \overline{U} + u$ - being reflected on the pressure values acting on the external openings.

So, from a constant pressure value, P_k, out of a non time dependent wind velocity, U,

$$P_k = \frac{1}{2} Cp\ \rho\ U^2 \tag{1}$$

a pressure fluctuation, p_k, arises and the mean value, $\overline{P}_k$, where a term including the turbulence intensity shows up, when U is replaced by $U = \overline{U} + u$

$$[P_k =]\frac{1}{2} Cp_k \rho\ (\overline{U} + u)^2 \Rightarrow [\overline{P}_k =]\frac{1}{2} Cp_k \rho\ \overline{U}^2\ (1 + I^2) + [p_k =]Cp_k \rho\ \overline{U} u \tag{2}$$

where Cp_k is the k^{th} external opening pressure coefficient, ρ is the air density and I is the turbulence intensity defined as,

$$I = \frac{\sqrt{\overline{u^2}}}{\overline{U}} \tag{3}$$

The ABL is currently represented by a turbulence intensity and a vertical mean velocity profile. For this model a more accurate description has to be used in order to consider it's time and length scales. The velocity fluctuation component is characterised in the frequency domain through the power spectral density function (the Davenport "spectrum" being adopted) – $S_u(n)$- for the alongwind direction (where the energy content his higher for the larger eddies) being weighted by a transfer function in order to obtain the "effective spectrum" - $S'_u(n)$ - that determines the air change rate variations around the mean value. Assuming an homogenous turbulence and instantaneous transmission associated with the absence of damping for the internal pressures – meaning that, on the present model stage, pressure fluctuations are integrally transmitted inside the building – the ACH rates may also be characterised by a standard deviation superimposed on the mean value.

It's the value of that standard deviation that increases the knowledge of possible, and statistically significant, situations of discomfort namely excess of internal air velocities or insufficient heat, or pollutant, removal.

VENTIL MODEL

An estimate of a NV process for a building with a number of internal spaces is characterised by the knowledge of the flow velocity through any opening and the pressure, temperature and density variation for each one of the spaces.

VENTIL assembles a set of non linear equations allowing to achieve that target:

- A mass balance equation for each space and the overall building. In addition flow velocities for any opening of connecting spaces must cancel;
- A momentum balance equation (Bernoulli eq.) for each opening;
- An energy balance equation for each space, and;
- The perfect gas law.

Concerning the input parameters it should be specified that if pressure coefficients are referred to the building eaves height wind velocity, the ABL is already being taken into account and so surface shear and turbulence intensity are determined. In fact considering the Davenport "spectrum" one may write,

$$I = \frac{\sqrt{\overline{u}^2}}{\overline{U}_{10}} = \frac{1}{\overline{U}_{10}}\left[\int_{-\infty}^{\infty} S_u(n)dn\right]^{1/2} = \sqrt{3\,C_{f10}}\left(\frac{y}{10}\right)^{-\alpha} \tag{4}$$

where I is the turbulence intensity, u is a velocity fluctuation, U_{10} is the average velocity 10 m a.g.l., both in m/s, C_{f10} is the surface shear coefficient, y [m] is the distance from the ground and α is the exponent of the power law describing the ABL velocity profile. A relation between C_f and α may easily be established.

Now the dimensions of the eddies must be evaluated because the influence of the turbulence on the ACH rates comes through the external openings. The larger eddies may be considered on the average and the ones smaller than the smallest opening dimension cancel between themselves. So the lowest limiting frequency for the transfer function, corresponding to the dimensions of those eddies the contribution of which can be considered through an average and then as arriving from a 'quasi-stationary' process, is given by,

$$n_1 = \frac{\overline{U}_{10}}{L} \tag{5}$$

L being the eddy alongwind length which, in the conceptual eddy, is related with the other two dimensions: L_2 on the cross dimension and L_3 on the vertical one. If the opening is clearly wider on the cross dimension, then $L=16*L_2$. On the other hand, for a more "square" opening, $L=10*L_3$. Actually those coefficients are not constant and should decrease with the distance to the ground and increase both with the mean velocity and the ground roughness. The higher frequency, n_2, is a cut off frequency thus assuming the existence of an "inertial" process and in terms of simplicity assumed to be one order of magnitude larger than n_1.

The transfer function has a unity value up to n_1, a zero value over n_2, and assumes a linear decrease to zero in between. The spectrum is then weighted by this transfer function in order to obtain the "effective spectrum" - $S'_u(n)$ - that will allow to estimate the air change fluctuations (rms value).

RESULTS

Two side by side identical industrial buildings was used as an illustration of the model application and capabilities. The choice of those buildings is justified by the fact that a scale model had previously been tested on wind tunnel under different boundary layers and it's pressure coefficients measured.

The buildings main features are (Fig. 1): planform area of 1600 (=80*20) m^2; volume of 10144 m^3; one external opening on each side (30 m^2) and one at each roof summit (30 m^2), and one communicating opening (15 m^2). The wind blows at 5 m/s (eaves height) from left to right normal to the façade and the outside temperature is 15°C. There's a small heat source of

3500 W on the leeward building. Three ABL were considered, the power law exponents being respectively: α_1=0.10 (near a large mass of water); α_2=0.14 (open field); α_3=0.22 (industrial park).

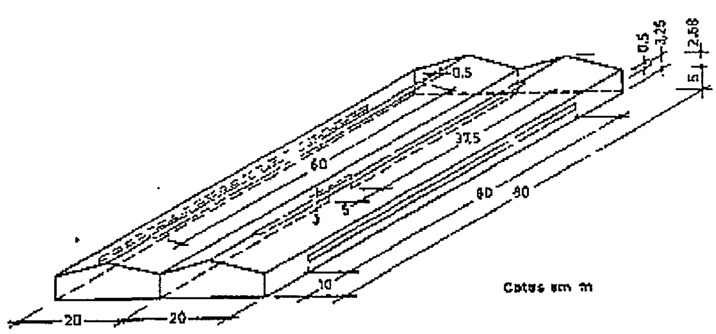

Figure 1 – Buildings layout and dimensions

Results are presented on fig. 2 as follows: the sequence of ABL goes from α_1 to α_3, right to left; one ACH value for each α when no turbulence is considered (•); again for each α the standard deviation superimposed on the mean values keeping Cp values constant (and equal to the ones corresponding to α_1 - ◆) and varying Cp values with ABL (★). The arrows inside the circles show the flow direction through the openings.

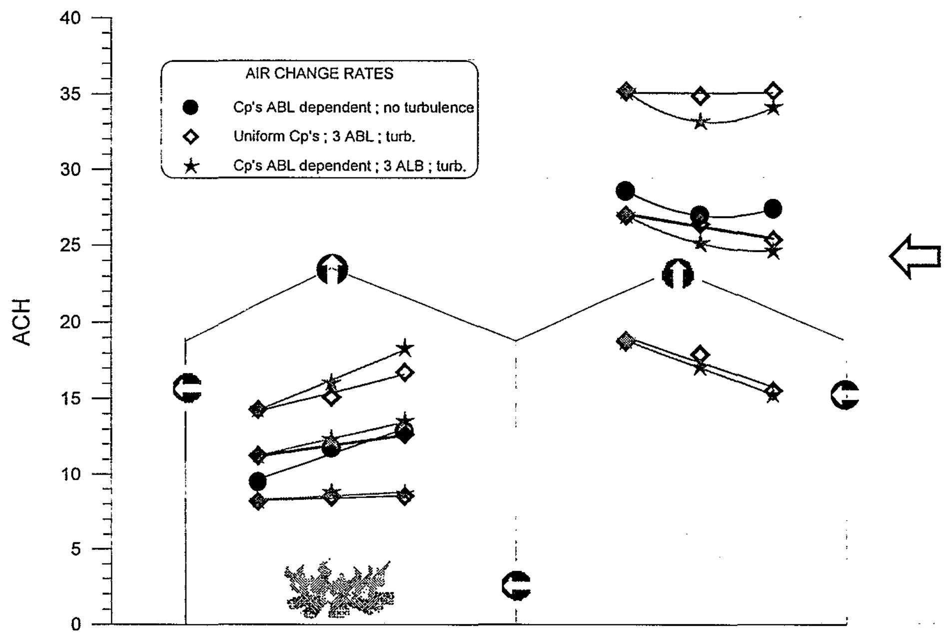

Figure 2 – ACH rates for different wind conditions

The first case corresponds to eq. (1) where the wind velocity depends only on the ABL but remains constant in time, and so there are no pressure fluctuations, leading to a single ACH rate value for each type of ABL. For the second case turbulent wind velocity fluctuations are introduced leading to the ± rms pressure fluctuations – p_k on eq. (2) – and their correspondent ACH values. The third case repeats the last one only changing the Cp values according to the ABL characteristics.

CONCLUSIONS

As it is shown there's no significant difference between mean ACH rates for the three cases, but when velocity and then pressure fluctuations are considered a change the standard deviation of ACH is around ±30% to ±40% from the mean value. The same changes are expected for the velocities through the openings with direct influence on comfort evaluations.

This model considers that eddies influence the whole building at the same time. In fact this influence depends on both the building and eddy dimensions. The time gap on the turbulence influence on different external openings is now under development.

REFERENCES

Saraiva, J.G., Effects of atmospheric turbulence on industrial buildings (in Portuguese), 1985

Saraiva, J.G.; Dias, J.; Janeiro Borges, A.R., VENTIL – a software tool for NV (in Portuguese), LNEC, 1985

Saraiva, J.G.; Dias, J.; Janeiro Borges, A.R., Industrial buildings – Actions, interference and natural ventilation (in Portuguese), LNEC, 1985

Saraiva, J.G., A non dimensional approach to ventilation, 1st World Renewable Energy Congress, Reading, UK, 1990

Saraiva, J.G., Boundary layer characteristics in large industrial built-up areas, 1st World Renewable Energy Congress, Reading, UK, 1990

Marques da Silva, F.; Saraiva, J.G., Determination of pressure coefficients over simple shaped building models under different boundary layers, contribution to the PASCOOL project, EU, 1994.

Marques da Silva, F.; Viegas J.; Gonçalves da Silva, F.; Santos, P. R.; Saraiva, J.G., Ventilation and cooling, 19th Annual AIVC Conference (Poster session), Oslo, 1998