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NATURAL VENTILATION CHARACTERISTICS AND INDOOR AIR QUALITY OF BUILDINGS

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1.0 Synopsis

The importance of natural ventilation, typically restricted to residential buildings application, is rapidly increasing also within the commercial buildings. This is mainly due to the energy savings expected from a reduction of the use of the forced ventilation. Moreover, the remote control of the indoors, provided by means of the intelligent buildings features, allows an easier management of the environmental quality. Furthermore, the indoor air quality is also directly affected by the air exchanges obtained by natural ventilation. Flow rates are strongly influenced by the design characteristics of the openings and by the location of the building with respect to the external winds. On the other hand, the indoor ventilation rates are modified by people who properly operate the window sashes. Using a computer code developed by some of the authors and validated by comparison with experimental data provided by Ispra Joint Research Centre, a comprehensive set of graphs is introduced, in order to check the suitability of the natural ventilation in bringing well conditions of life to the occupants. Fanger's theory based on "olf" and "decipol" methodology has been used for the definition of the indoor air quality levels. Graphs, for assigned geometries of the building and layout of the openings, and for given pollutant sources, give both the proper amount of the flow rate necessary for attaining an assigned percentage of dissatisfied and the flow rates provided by the natural ventilation. By facing these values, it is possible to establish whether the natural ventilation is sufficient or not to ensure the requested air cleanliness.

2.0 The perceived air pollution

Following a recent methodology proposed by P.O. Fanger and coauthors (1) it is possible to determine the ventilation rates to be provided inside a building in order to bring well being conditions to the occupants.
Unlike current standards, Fanger's procedure takes into account the quality of the external air and allows a measure of the internal pollution sources. The quality of the air and the pollution produced by a given source are checked by the computation of the quantities "olf" and

"decipol". The olf measures the emission rate of bioeffluents from a standard person, while any other source is considered as it was that number of standard people who would cause the same effects of the present pollutant source. The decipol is the pollution produced by one olf under a ventilation rate of 10 l/s of clean air. By relating the olfs subjected to different levels of ventilation with the dissatisfaction of judges that find the air quality unacceptable (2), it is possible to establish a link between the percentage of dissatisfied judges and the ventilation rate. Thus the flow rate Q_r required for obtaining the desired quality of the indoor air is (3):

$$Q_r = 10\frac{G}{C_i - C_o}\frac{1}{\varepsilon_v} \tag{1}$$

where G = the global pollutant sources [olf]; C_i = the perceived indoor air quality [decipol]; C_o = the perceived outdoor air quality [decipol]; ϵ_v = the efficiency of the ventilation system. The parameter C_i is related to the percentage of dissatisfied PD by means of the equation:

$$C_i = 112\,[\ln(PD) - 5.98]^{-4} \tag{2}$$

2.1 Evaluation of air flow rates related to the natural ventilation

A computer program for evaluating the air flow rates in a cross-ventilated room has been recently proposed (4). NATVE model provides the ventilation rates under some simplified conditions and it is based on the most consolidated developments in the field (5) and it has been validated using experimental data provided by ISPRA Joint Research Centre (6,7). The air flow rate Q_v is computed by means of the following equation:

$$Q_v = A \cdot v \prod_{i=1}^{6} K_i \tag{3}$$

where A = the inlet free opening area; v = the wind speed; K_1 = the discharge coefficient; K_2 = the wind presure coefficient; K_3 = the inlet-outlet area coefficient; K_4 = the inlet-outlet distance coefficient; K_5 = the internal partition coefficient; K_6 = the fly-screen coefficient.
Typical values of the coefficients can be found in (5) NATVE candidates itself as a very simplified procedure to compute the air flow rates in a room where all the windows are open, for this it takes into account only the effects related to the wind pressure and only requires as input data the geometrical parameters of the building and of the openings, the wind speed and direction. Being only a simplified model, NATVE does not take into account the temperature effects or infiltractions or the presence of other near buildings; however, it can

take into account the presence of centre-pivot-hung sashes, fly-screens and internal partitions. Using more complex models, we will surely obtain more accuracy in the results, but the philosophy of the method here presented remains unchanged.

3.0 Method of analisys

In an earlier paper, some of the authors, presented some pictures that translate in a graphical form the results obtained through the application of the NATVE model to some rooms having different geometries, purposes, number of occupants, internal pollution sources and external air quality. Three cross-ventilated rooms have been selected here, whose characteristics are reported in Tab.1 and in figs. 1a, 2a, 3a.

Tab. 1

	Case 1	Case 2	Case 3
Building Type	Office	Residential	Residential
Floor Area [m^2]	8 x 4	8 x 4	10 x 4
Volume [m^3]	96	96	120
No. of Windows	2	4	2
No. of Occupants	6	5	3
Perc. of smokers	50	20	0
C_o [decipol]	0.2	0.5	1
Pollutant Sources [olf/m^2 of floor]	0.15	0.10	0.05
Ventilation Efficiency	1	1	1
Perc. of Dissatisfieds	20	20	20

The graphs of Figs. 1b, 2b, 3b show the response of the rooms depicted above, in terms of air flow rate, to the wind speed and direction. Indeed, it is very hard to find on these graphs flow rates related to the angles of incidence different from that for which the calculation was made; this is why the relation is very complex between flow rates and wind direction. This relation that costitutes a specific characteristic of a room with its openings, and that we will name here "ventilability", is represented in figs 1c, 2c, 3c. Ventilabilty graphs was built using the angle of incidence of the wind and the values of the flow rates calculated by NATVE, divided by the flow rate related to a fixed reference angle. In Figs 2a and 2c the reference angle is 0°, in fig. 2b the reference angle is 90°. Adopting the linear relation between flow rate and wind velocity shown in figs 1b, 2b, 3b we can use in a very simple way the "ventilability" graphs for any value of wind velocity from 0 to 0.5 m/sec. Therefore, knowing the values of the wind velocity v and of the wind direction ø, it is possible to determine the value of the flow rate Q_v:

$$Q_v-K(\varphi)\cdot v\cdot\frac{Q_\varphi}{Q_{0^\circ}}(\varphi) \tag{4}$$

where $Q_{\o}/Q_{0^\circ}(\o)$ is the ventilability function calculated once and for all for a given room and referred to a specified window or opening (called here "active"), K(ø) relates, in the above hypotheses, the values of the flow rate with the velocity of the wind blowing perpendicularly through the active window. By comparing the value of Q_v with the flow rate Q_r referred to a standard pecentage of dissatisfied (viz. 20%) (8) it is possible to verify whether the natural ventilation is sufficient to ensure the desired IAQ or it is necessary to have resort to mechanical aids.
In some instances a flow rate Q_v can be found that largely exceeds the ventilation requirements, so the indoor air velocity could become annoying. In this case it would be advisable to reduce the air flow rate properly operating the centre-pivot-hung sashes of the active window.
Fig.4, referred to the active window of fig. 1a, shows the effect of position of the openable sashes on the air flow; in this picture air flow rates are divided by the value of the flow rate passing through the window when the sashes are fully open. We have to rewrite eq.4 in the following form:

$$Q_v-K(\varphi)\cdot v\cdot\frac{Q_\varphi}{Q_{0^\circ}}(\varphi)\cdot\frac{Q_\alpha}{Q_{0^\circ}}(\alpha) \tag{5}$$

The knowledge of the function $Q_\alpha/Q_{0^\circ}(\alpha)$ makes it possible the automatic regulation of indoor air flow rate by a remote-controlled servomechanism acting on the angle α of the sashes of the active window. It will be observed that this kind of control shows a real effectiveness only for the rooms of figs 1a and 3a. In these cases, in fact, there are only two windows, so the inlet or outlet air flow must pass through the active window, and the shape of the ventilability curves 1b and 3b does not change. The room of Fig.2a has three openings and there are some instances in which the wind does not blow through the active window (90°). Fig.5 shows the variation of the shape of the ventilability curve for the room 2a as a function of the sash angle α.
It will be noticed that in such a case the effectiveness of the control system is largely reduced. By combining together Eqs (1) and (2) and taking into account the influence of the sash angle α, it is possible to draw the graphs of figs.1d, 2d and 3d. The graphs show the relationship between the percentage of dissatisfieds and the sash angle α for some values of the velocity of the wind blowing perpendicularly through the active window.

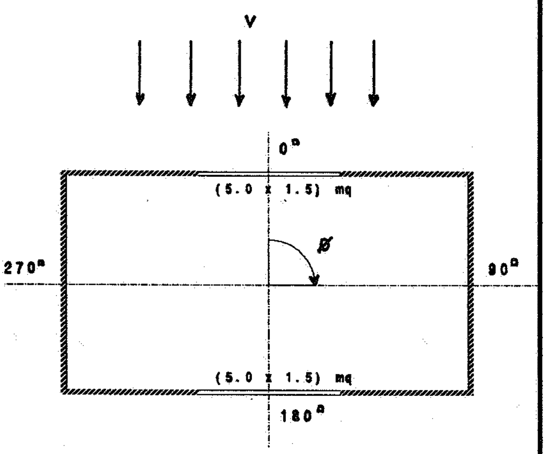


Fig.1a - Sketch of the case 1 room, with the layout of the windows

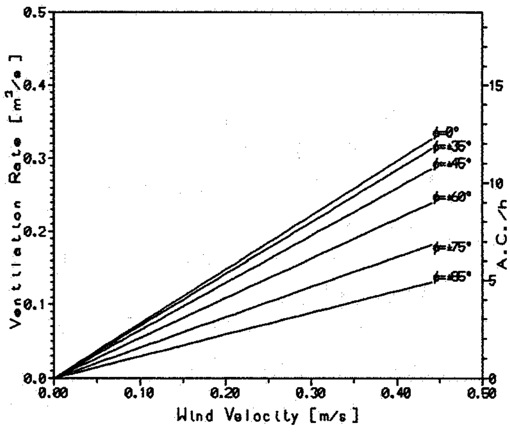


Fig.1b - Relationship between ventilation flow rates and wind velocity.

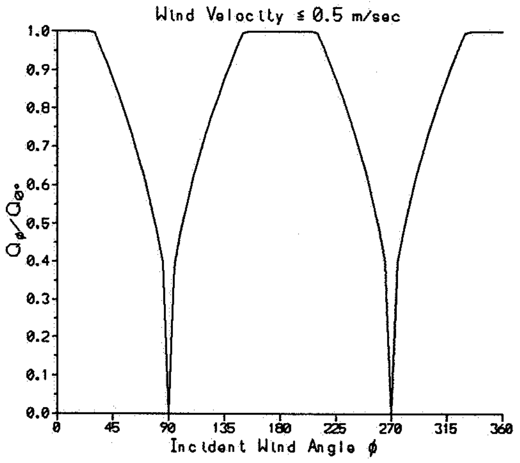


Fig.1c - "Ventilability" of the case 1 room.

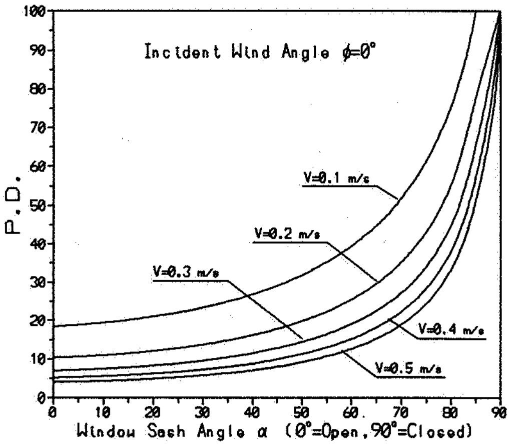


Fig.1d - Percentage of dissatisfied people as a function of the sash angle, α.

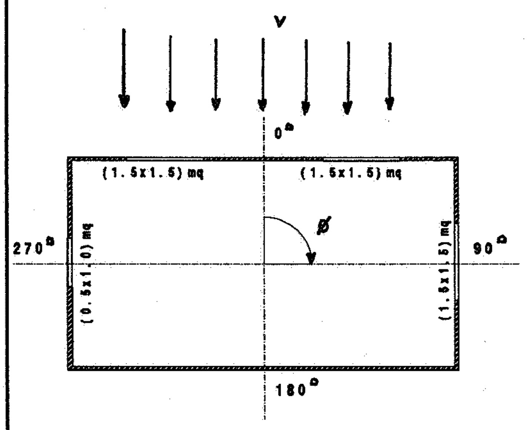


Fig.2a - **Sketch of the case 2 room, with the layout of the windows**

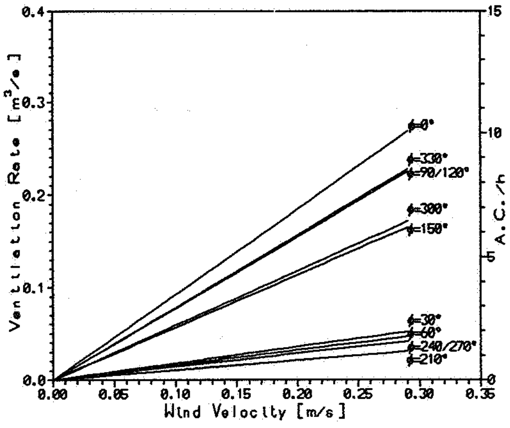


Fig.2b - **Relationship between ventilation flow rates and wind velocity.**

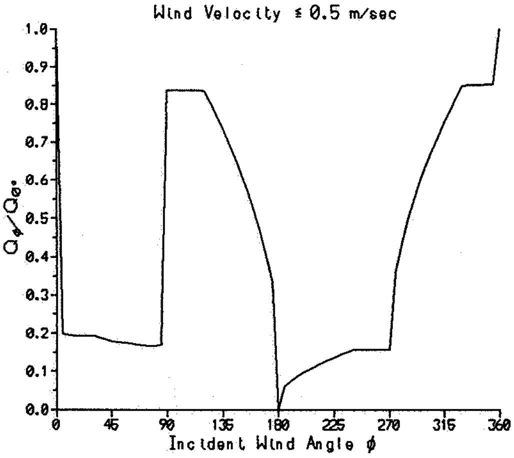


Fig.2c - **"Ventilability" of the case 2 room.**

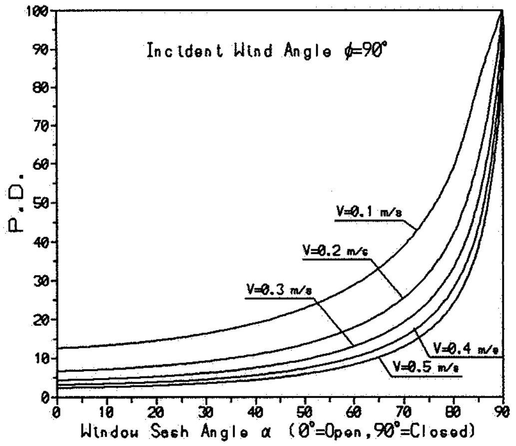
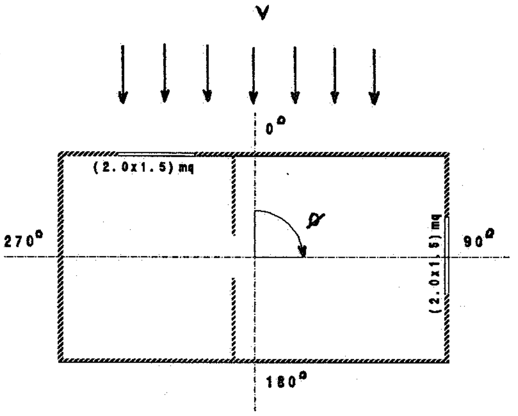


Fig.2d - **Percentage of dissatisfied people as a function of the sash angle, α.**



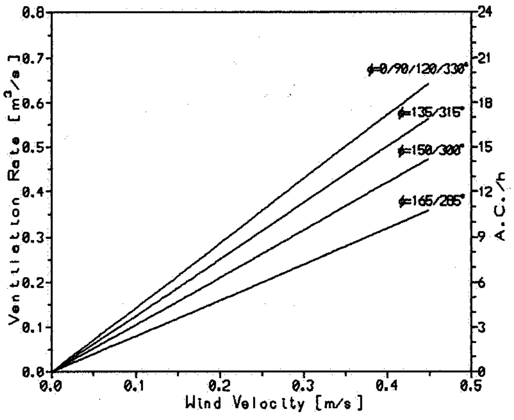
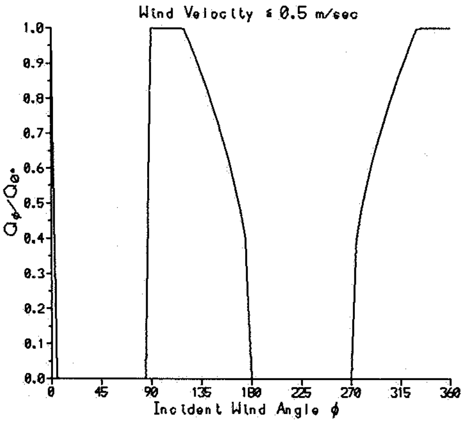


Fig.3a - Sketch of the case 3 room, with the layout of the windows

Fig.3b - Relationship between ventilation flow rates and wind velocity.



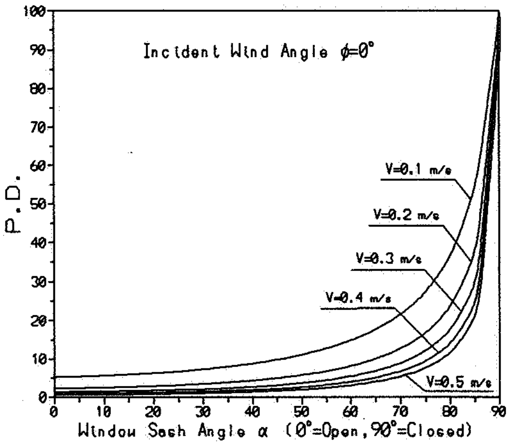
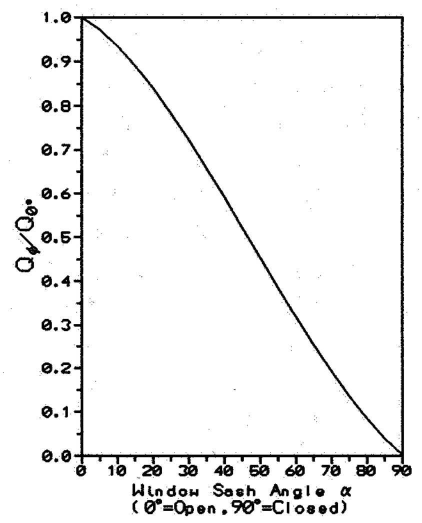


Fig.3c - "Ventilability" of the case 3 room.

Fig.3d - Percentage of dissatisfied people as a function of the sash angle, α.



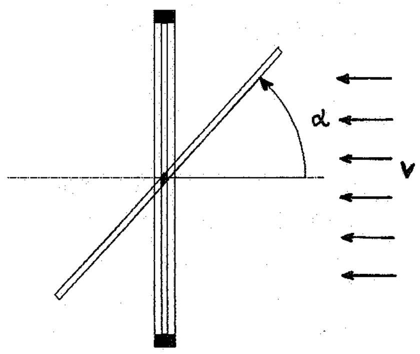


Fig.4a - Flow rates as a function of the angle of the openable sash.

Fig.4b - Sketch of the window equipped with a sash.

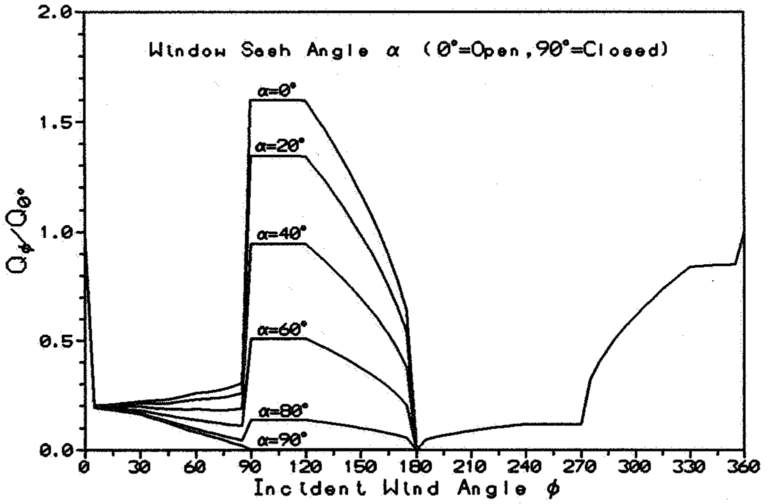


Fig.5 - Variation of the ventilation shade as a function of the incident wind angles.

4.0 Conclusion remarks

Through this paper we have introduced the "ventilability" curves as a simple but comprehensive way to represent the ventilation characteristics of a given room. The relationship between flow rates and wind direction has been obtained using the NATVE model. As far as the intelligent building features are concerned, simple and fast-running programs like NATVE can be used on-line by the control system and could be easily modified whenever we have to change a relevant parameter of the room. Results obtained using more accurate and complex models could be transferred once and for all in a ROM or in a look-up table which are indeed fast to read but hard to modify. Generally speaking the simplified methodology here outlined makes itself an useful tool for the identification of appropriate choices at the early stages of the design process regarding naturally ventilated buildings.

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