Natural ventilation efficiency in apartment and Reynolds analogy in a water channel

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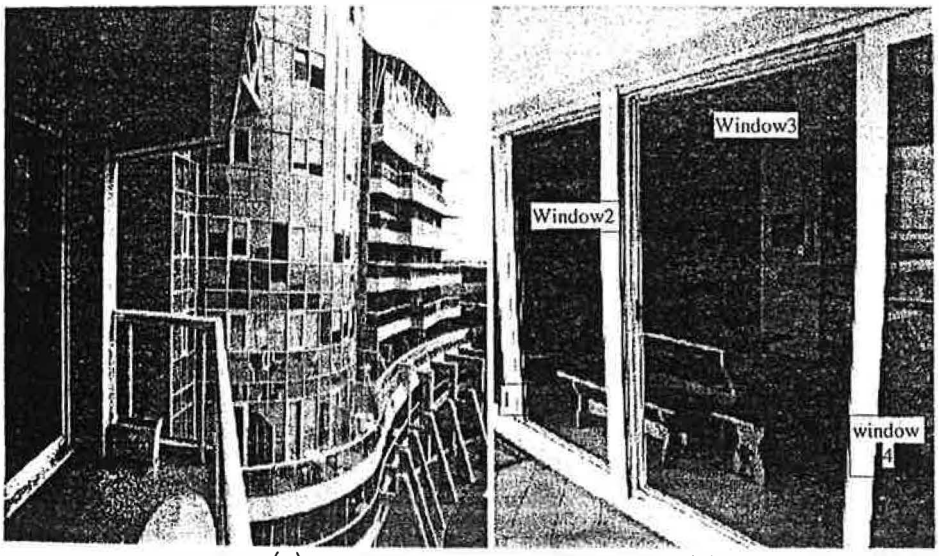
Introduction: Within the frame of ALTENER/AIOLOS [1] programme of the European community experiments have been carried out in order to study the efficiency of natural ventilation in a real apartment. In this study, through the experiments occurred during the last July and August, natural ventilation effects have been thrown into relief. The cooling effect induced by natural ventilation has been shown by the resultant temperature results and the efficiency coefficients enable us to show clearly the quality of natural ventilation in relation with the opening strategy. For the Reynolds analogy, the aim of study was to define an experimental protocol in order to visualise air flow patterns in naturally ventilated building.

1. Site characteristics and building description

«Porte Océane» is located just in front of the ocean. The building has a facade of white stone and glass so that every inhabitant get a fantastic view on the ocean. The south facade shows the searching for openings and transparency given by the integration of large windows and balconies. The local climate is typical of the temperate climate. In summer there's a quite large amplitude between night and day (11 - 12 °C in August). Nights temperatures are cool. This apartment has got the advantage to present a large balcony in front of the ocean. Inside of the apartment there' s one large room (26 m²) with a window (11.32 m²) like a loggia bay.



(a) (b)

Fig. 1 : (a) The apartment(5th floor of the building) (b)The window pane

The window pane is of 5.10 m width and is divided in 4 sliding sections of the same surface. It's striking to notice that the window is front of the ocean, it's suppose to have an important impact of natural ventilation if the window is opened. In the following experiments, CMV (Controlled Mechanical Ventilation) is closed or opened. CMV is a mechanical system which permits to exhaust pollutant in the kitchen, the bathroom and the toilet. It's located near the pollutant source, at the ceiling. When CMV is opened, it exhausts 0.7 volume per hour.

2. Weather characteristics during the experiments

Table (1) gives the wind characteristics (velocity and direction) for each experiment. The first one is measured in meter per second. The second one is measured in degree. 0 and 360 to the North, 90 to the East, 180 to the South and 270 to the West.

Experiment	n°	Wind Speed (m/s)	Wind Direction (deg.)	Configuration
July	1	2,5	50	Window3: opened CMV, Doors: closed
August	1	4	30	Window1, CMV: opened Doors: closed
	2	4	30	Window1, CMV, Doors: opened
	3	6	320	Window1&4, CMV: opened Doors: closed
	4	7	330	Window1&4, CMV: opened Doors: closed
	5	8	330	Window1&4, CMV, Doors: opened
	6	6,5	340	Window2&3, CMV: opened Doors: closed
	7	4	350	Window2&3, CMV, Doors: opened
	8	2,5	300	Window2&3, CMV, Doors: opened
	9	3,5	75	Window1, CMV: opened Doors: closed
	10	4	75	Window1,CMV, Doors: opened
	11	4	75	Window1,CMV, Doors: opened
	12	2	20	Window2&3, CMV: opened Doors: closed

Tab. 1 : The Configurations

3. Thermal behaviour of the building during summer

The experimental results are described in the two following parts, the first one shows the results of the July experiments and the second one analyses those of the 12 experiments carried out during the August period.

3.1 Cooling effect induced by natural ventilation : Our interest concerns especially the black bulb temperature. Indeed this temperature is the most representative to express the thermal sensation feeling of the user. As can be seen in the first graph, there's a 7 days period with the same exterior conditions. During the 3rd one, window 3 was opened. Fig. 2 shows that the black bulb temperature is lower when the window is opened, it's the direct effect of natural ventilation.

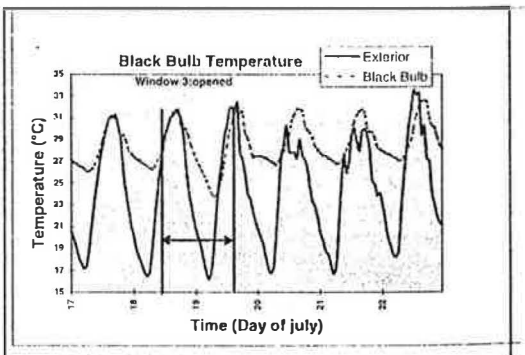


Fig. 2: July experiments results

An other important point is that the black bulb curve has an amplitude of 7 °C while this of the exterior has an amplitude of 15°C. In addition, there's a difference in phase of about 1 hour. That shows the apartment inertia effect, the apartment structure reduces and alters the important outdoor temperature oscillations. Indeed, the external walls are made of concrete blocks with an exterior insulation and the floor and the ceiling are made of concrete slab, so the apartment has a high inertia. It would be important to take this fact into consideration when the object of designing night ventilation for example.

3.2 Natural ventilation efficiency: The figure (3.a) shows the evolution (Decay Method) of concentration in the centre of the room. We observe an important decrease of concentration (ppm) which concerns the three cases of opening (window 1 opened, window 2&3 opened, window 1&4 opened). In each case of opening (surface of the opening is 2.83 m² or 5.66 m²): the decrease of SF6 is very quick, compared to the decrease concerning the permeability of the room.

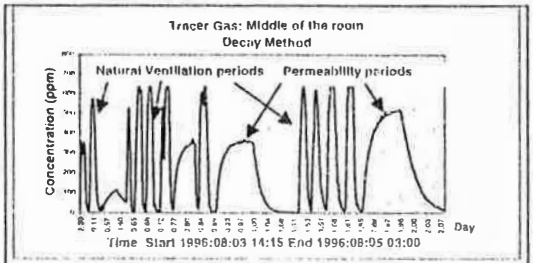
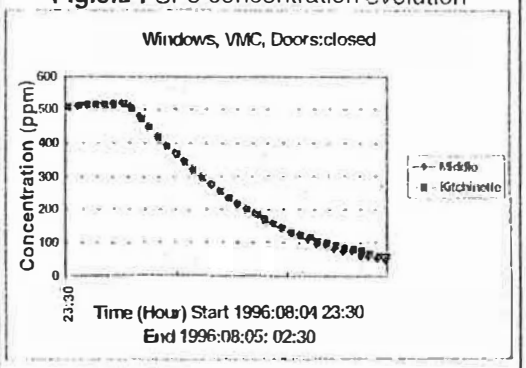
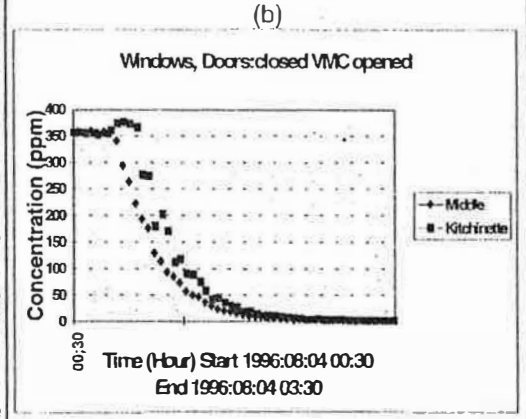


Fig.3.a : SF6 concentration evolution



(b)



(c)

Fig. 3.b,c : Tracer gas results (no openings)

The two following graphs (fig. 3.b and 3.c) show the CMV effect on the air renewal. When CMV is closed, the efficiency coefficients for the central point (61.78%) and kitchenette (60.81%) are the same (difference of only 1%). But when CMV is opened there's a drop of kitchenette efficiency coefficient, mostly 20% (the central one is 57%). This can be explained by the fact that the extraction opening is located in the Kitchenette ceiling. It's striking to notice that only central and kitchenette results have been reported in the graphs because on the one hand middle, east, west and ceiling comportment and on the other hand kitchenette and corridor are the same. As can be seen in figures 4.a and 4.b, for the same lapse of time (about 20 minutes), the double quantity of gas has disappeared when the windows 1 and 4 are opened (compared to the case of one opening window). Moreover the opening of two windows has lead to have a good air renewal, so there was not an accumulation at the ceiling.

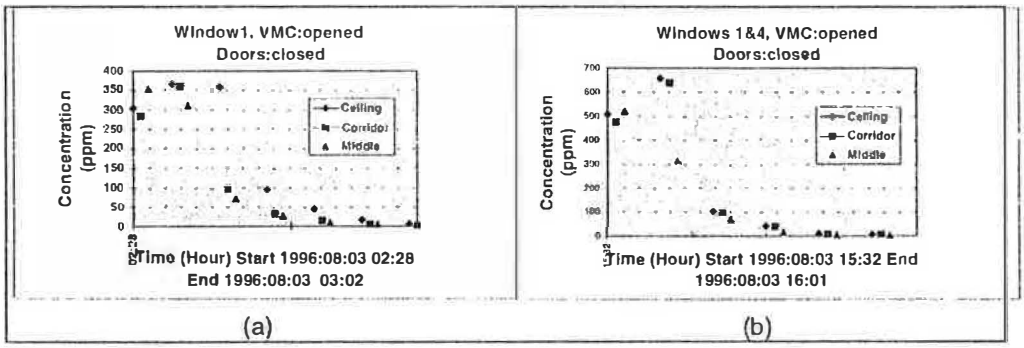


Fig. 4 : Tracer gas results (openings)

The geometrical average is calculated averaging on the 6 points which are uniformly distributed in the room. Several remarks can be done : Firstly, the CMV impact is very weak, it represents only 1 or 2% modification of the efficiency coefficient. Secondly, the fact of opening two windows is better than opening one window but it's striking to notice that, when the lateral windows are opened, the efficiency is 18% higher. This can be explained by the fact that when the lateral windows are opened, a draught appears and permits a better mixing of inside air.

	Bathroom & WC doors	Experiment	Geometrical average (%)
Window 1 opened	closed	1	68,34
	opened	2	69,21
		11	71,63
Window 1&4 opened	closed	3	87,45
Window 2&3 opened	closed	6	71,7
		12	69,67
	opened	8	71,34

Tab.2 : Efficiency coefficients

The efficiency is calculated by : $$\varepsilon = \frac{\tau p}{2 < \tau >} \quad (1)$$

with : τ_p is the local mean age $$\tau_p = \int_0^\infty \frac{C(t)}{C(0)} dt \quad (2)$$

$<\tau>$ is the room mean age $$<\tau> = \frac{\int_0^\infty t C(t) dt}{\int_0^\infty C(t) dt} \quad (3)$$

C(t) : SF6 concentration at the measurement point. Finally, comparing the efficiency coefficients of experiments 6 and 12, we can see that these two coefficients are similar. Nevertheless the wind velocities are different (6 m/s during experiment 6 and 2 m/s during experiment 12). So the conclusion is that, when the wind velocity reaches a certain threshold, the ventilation efficiency stays on the same level even if the wind velocity is still increasing.

4. The scale model in the Hydraulic channel

The aim of this study is to define an experimental protocol in order to visualize air flow patterns in naturally ventilated building.

From a fluid mechanics point of view, there is a direct similitude between two flows with the same Reynolds number. Around 20°C, there is a ratio of 20 between the viscosity of water and air, which means that, for the same characteristic velocity between the reality and the model, the geometrical dimensions can be reduced by an order of 20 times.

The facility is a 20 m long water channel of 1m² section and a 7 Watt laser equipped with 30 m of optical fibre with different kinds of lenses [2]. The model, represents the « Porte Ocean » apartment and moves automatically along the channel (fig. 6).

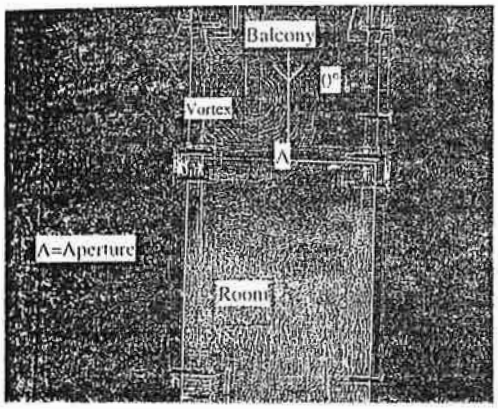


Fig. 5 : V=0.5 m/s, θ = 0°, balcony zoom

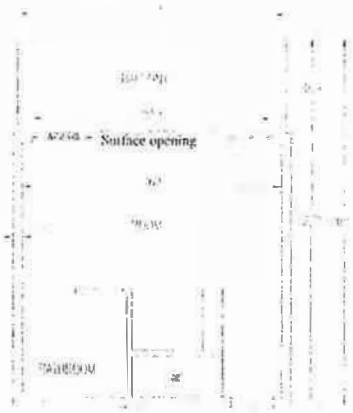


Fig. 6 : floor plan view of the scale model

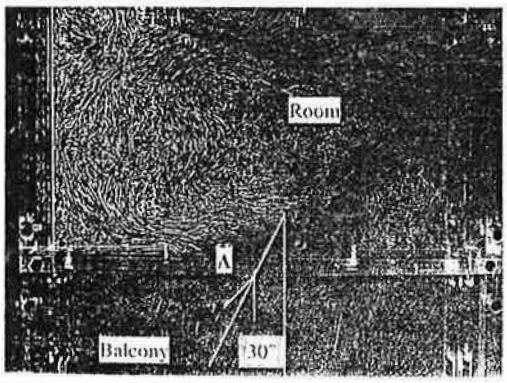


Fig. 7 : V= 0.5 m/s, θ = 30°, aperture zoom

Fig. 8 : The Balcony characteristics (mm)

The velocity covers a range from 0 to 7 m/s, representing external winds of the same characteristics. The data acquisition consists of photographs and video.

The aim of these experiments is to study single-side ventilation in a full scale building, under real climatic conditions, in order to: better understand the related phenomena, collect data for the validation of existing models (theoretical models and computational network models), and develop more accurate methodologies for the calculation of the air flow patterns in this specific case of natural ventilation. A scale model is conceived to provide the flow visualisation by Reynolds analogy in water channel. Indeed, we are interested in the velocity field of air, generated by an external wind in an apartment. The visualisation technique used Rilsan particles (density 1.06) which is very close to water density and leads to a very good transport in the flows (fig. 5).

The results consist of a video showing different configurations of air flow patterns in single sided ventilation with various angles of incidence upon the opening (fig. 5 and 7). It shows very clearly the different flow patterns that can be found in these configurations : inertial flow in room with a small circulation in aperture zone (the incidence value with respect to the normal of the opening in a single sided ventilation case is 0° induced a piston flow phenomena (fig. 5); and for case $\theta = 30°$ (Fig. 7) the concentration of particles localised in left of the room. This video is obviously a very good demonstration tool, but it is not sufficient to obtain quantitative data. There are also still photographs with different exposure times in order to obtain trajectory elements of the particles. These elements represent in fact velocity vector fields for different configurations.

Conclusion : In this study, through the experiments occurred during the last July and August, natural ventilation effects have been thrown into relief. The cooling effect induced by natural ventilation has been shown by the resultant temperature results and the efficiency coefficients enable us to show clearly the quality of natural ventilation in relation with the opening strategy. These results obtained by flow visualisation in a water channel demonstrate the suitability of this method to characterise the flow patterns. This methodology offers good perspectives to obtain a very detailed information about velocity fields.

Référence :

[1] ALTENER/AIOLOS CEC Research Programme. Programme, which was partly financed by the Commission of the European Union, DG XII for Science, Research and Development.
[2] Single Sided Ventilation, F. Allard and K. Limam (ed.) (1995), PASCOOL, Research Project, MDS/VTL Final Report, Ch. 2, EC DG XII, Brussels.

Acknowledgements :

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