#4520

International Energy Agency

Energy Conservation in Buildings and Community Systems

Annexe 20 : **Air Flow Patterns With Buildings**

Subtask 2 : **Multi–zone air and contaminant flow and related measurement techniques**

Research action : 2.1 **Flow through large openings**

WIND TURBULENCE AND VENTILATION

Date : June 6, 1990

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CONTENTS

1 - INTRODUCTION

One of the mainsprings of ventilation in buildings is the pressure due to wind. Because of its fluctuating character, wind produces a pressure field around a building which is also fluctuating (1, 2). However, most multi-zone numerical models for air transfer disregard this phenomenon by using a certain number of simplifying hypotheses including that of air incompressibility and that of the steadiness of wind pressure during the same period of time.

These simplifications lead to erroneous conclusions in certain cases. For example, when the pressure inside a room is equal to the wind pressure on the facade, taking temporal wind fluctuations into account produces an air flow rate which is not equal to zero. Similarly, when a room only communicates with the outside via a single opening, the air transfers are not zero, if both the air compressibility and temporal wind fluctuations are considered.

Research works have been conducted at the C.S.T.B. in order to assess the effect of wind pressure fluctuations on air movements inside buildings.

The influence of the effects of wind on ventilation was studied using a numerical model which includes air compressibility, together with the pressure field measured on a model in a boundary layer wind tunnel. The simulation results obtained are analysed. The effect of wind fluctuations on the quality of ventilation is evaluated using the concentration of a pollutant as an indicator.

The experimental validation of the computer code is now being undertaken using flowrates measurements in an experimental rotating house at Bouin (near Nantes). The measurement methodology is described and first experimental results are given in this report.

2 - NUMERICAL STUDY

2.1 - Model making

The SIREN 2 code is used (see figure 1) to evaluate the movement of air between zones within the same building under given temperature and wind pressure conditions and for ventilation installations and buildings with given characteristics. The pressure fields are determined (see figure 2) by taking measurements in a boundary layer wind tunnel on a 1/150 scale model [4].

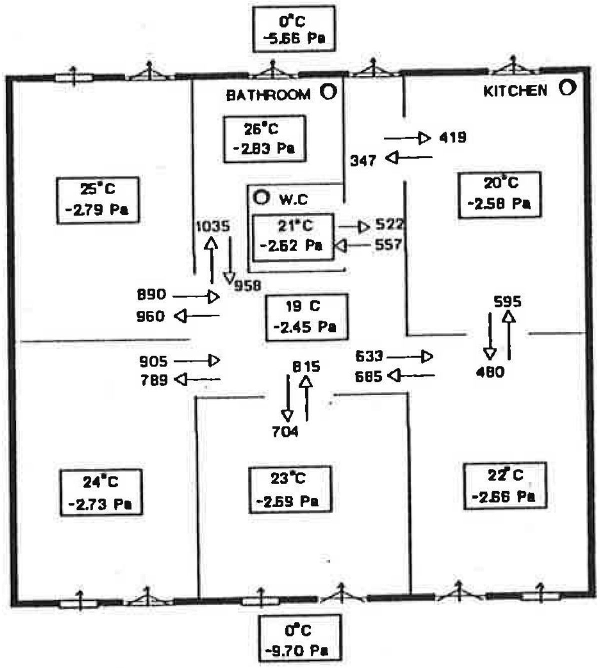


Fig. 1 :
Computed flow rates (in kg/h) in a dwelling with mechanical ventilation

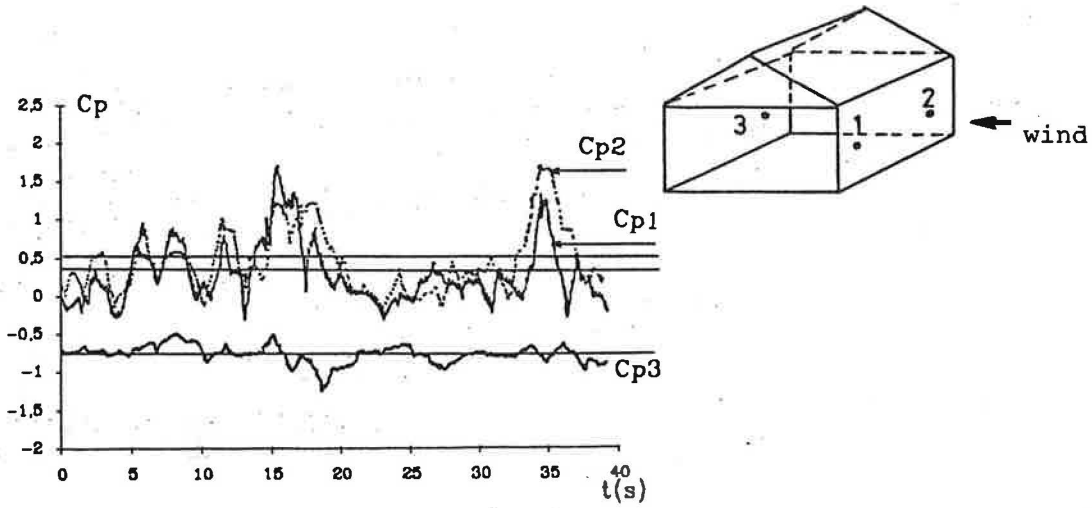


Fig. 2 : *Examples of spatial and temporal fluctuations in wind pressure*

For each zone i, the mass balance is :

$$\frac{dmi}{dt} = Qi \qquad (1)$$

mi : air mass in zone i

Qi : mass flowrate exchanged between zone i and other zones.

From equation (1) and assuming the ideal gas law, we obtain :

$$\frac{Vi}{rTi} \cdot \frac{dPi}{dt} = Qi$$

where Qi is a function of the pressures in zones

Vi : volume of the zone i

Ti : temperature in zone i

Pi : pressure in zone i.

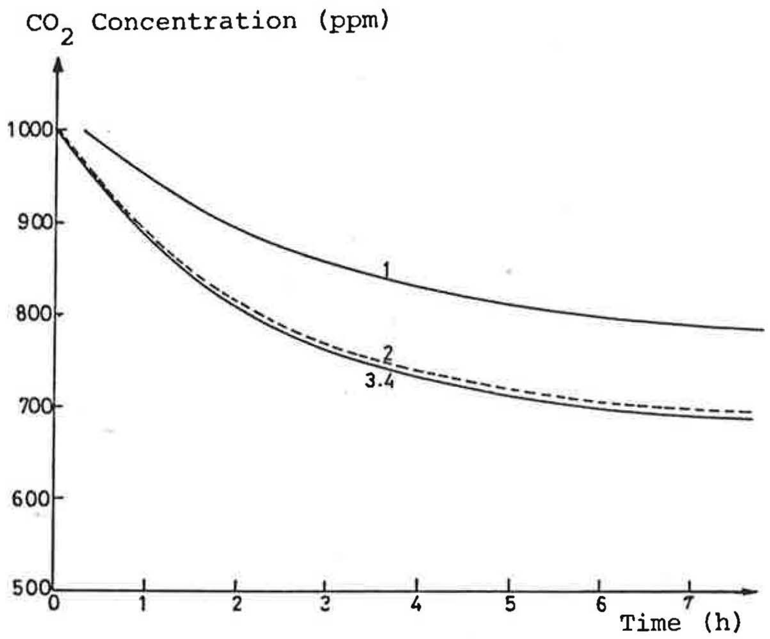
The differential equations system is solved using Levenberg-Marquart algorithm (minimization of the sum of the squares of a function).

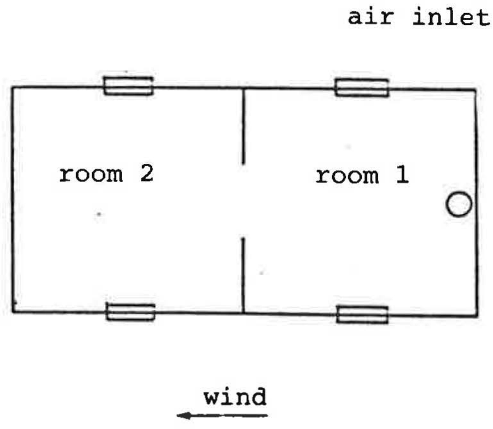
2.2 - Effect of wind turbulence on single-family houses

Air transfers are calculated according to different hypotheses depending on whether spatial and temporal fluctuations in the wind pressure and air compressibility are taken into account. In order to ascertain the effect of these hypotheses on the results, a pollution indicator is used i.e. the carbon dioxide concentration. Two cases were examined:

First case : study of a two-room house

The CO_2 concentrations were calculated in each of the two rooms for different wind angles and with the communication door closed and open. Figure 3, for example, shows the result of a simulation where the wind is parallel to the facades, the communication door is open and there is a constant flow of pollutant in room n° 1.





1 : incompressible air, constant wind pressure
2 : incompressible air, temporal wind fluctuations
3 : incompressible air, spatial and temporal wind fluctuations
4 : compressible air, spatial and temporal wind fluctuations

Fig. 3 : *Changes in the carbon dioxide concentration in room n° 2 as a function of time. Wind is parallel to the facades and communication door open.*

The results show that, unlike the air compressibility, the effect of wind turbulence cannot be ignored. The effect of temporal wind fluctuations on the ventilation is particularly important when the wind is parallel to the main facades (see figure 3) ; ignoring this can produce errors of up to 35 % in the CO2 concentration. However, the possible error committed by ignoring spatial fluctuations in pressure is less than 10 %.

Second case : study of a single room house

The case of a house with single exposure and no special ventilating system was considered. The air from the facade passes through a free section of 200 cm^2, while the opening in the opposite facade, corresponding to defective airtightness, is only 10 cm^2. It is assumed that no carbon monoxide is emitted inside the house and that the initial concentration is 1 000 ppm.

Figure 4 shows the changes in the carbon dioxide concentration as a function of time for various hypotheses. It can be noted that, unlike the previous example, the hypothesis of air compressibility is a determining factor. This is explained by the large disproportion between the sections of the two air passages (ratio of 1 to 20).

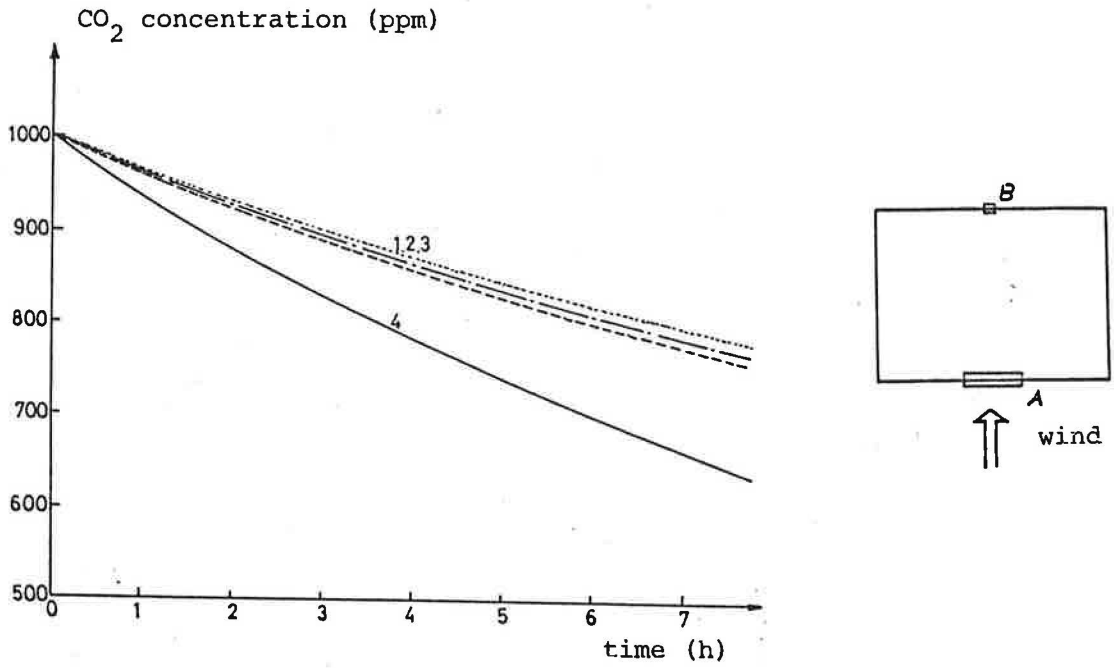


Fig. 4 : *Development of the carbon dioxide concentration with time (refer to figure 3 for meaning of hypotheses 1, 2, 3 and 4).*

2.3 - Effect of wind turbulence on a whole-house ventilation system

The effect of wind fluctuations on a seven floor building ventilated by collective passive stock ventilation [7] have also been investigated. Emissions of carbon monoxide with constant flow rates equal to 1 200 g/hr and 60 g/hr respectively on the fourth and top floors of the building were considered. The air transfers were analyzed for various hypotheses depending on whether or not spatial and temporal fluctuations in wind pressure were taken into account (the air is considered to be incompressible). The results show that taking the wind fluctuations into account considerably modifies the instant flow rates and can explain why the air flow is reversed on the top floor when the network head loss is high (figure 5).

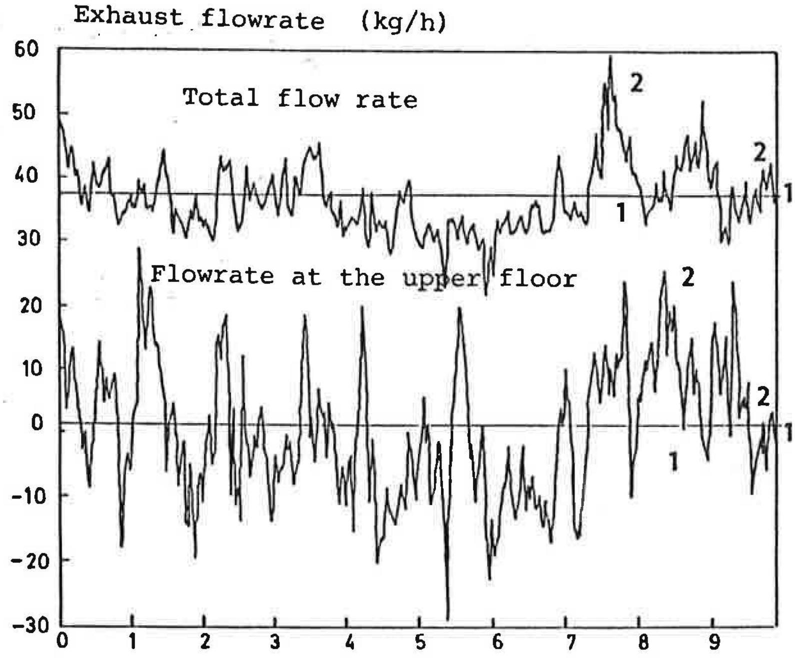


Fig. 5 : *Computed flowrates in a shunt duct*

1 : flowrates are calculated using time averaged wind pressure
2 : flowrates are calculated using actual wind pressure records

3 - EXPERIMENTAL STUDY

An experimental house was designed to globally validate the design codes by dealing with problems which it is impossible to simulate on a scale model in a boundary layer wind tunnel due to the lack of similitude. This is the case when determining the effective ventilation rates in a house, because the head loss is not a linear function of the flowrate.

3.1 - Experimental house

The experimental house is located at BOUIN, near the sea, in a windy site (wind velocity is about 5 m/s at 10 m height over open country). It is a dormer house (pitch of the roof is 30°) with dimensions : 9m x 5m x 4m (see figure 6). The BOUIN experimental house is a rotating house which can be turned toward a given direction of wind. At BOUIN, the variations of the direction of the wind are low for a day.

Fig. 6 : *Outside view of the BOUIN experimental house*

Particular care has been taken to make the walls of the house perfectly airtight so that air will only pass through the required areas. Air leakage flowrate is 30 m^3/h at 200 Pa, i.e. effective leakage area is less than 5 cm^2.

3.2 - Instrumentation

Pressure tapping points are distributed along the outside surface of the walls, and next to the air inlet and outlet orifices. The speed and direction of the wind are recorded in synchronization with all the measurements taken in the laboratory. The ventilation rate is measured in the conventional way using the tracer gas method. This instrumentation is completed by a chain of rapid response (40 Hz) measurements (8), (9) currently being installed and designed to instantaneously measure the flow of air entering or leaving the orifices or walls.

3.3 - Tests

Various tests were carried out in order to measure air change inside the house. Different configurations and parameters were studied :

- for single sided ventilation, the opening (100 or 200 cm^2) is located either windward or leeward ;

- for double sided ventilation, both openings are located in the same façade (to windward or to leeward), far away in height from 1.75 m. The case with two openings located on two opposite façades were also studied.

The test procedure is as follow :

- orientation of the experimental house

- sealing of the opening

- injection of the tracer gas (ethane) at 1 000 ppm

- homogenization of the gas inside the volume during 10 minutes, using mixing fans

- data logging:data are recorded in synchronization, the acquisition frequency is 5 Hz, the test period is 20 minutes.

3.4 - Results

The tests are now being processed and analysed.

The result of one test is presented below.

In this test, the ventilation is operated thanks to a single opening located windward. The tested opening is a slot of 100 cm^2 (2,5 x 40 cm) which is located at 2.05 m above the ground level.

The intensity and the direction of the wind are quite stable (see figures 7 and 8) : during the test period, the mean velocity is 7.7 m/s and the standard deviation is 1.2 m/s.

The fluctuations of the dynamic pressure at the opening are shown in figure 9 : the mean value is 13.2 Pa and the standard deviation is 9.1 Pa.

The figure 10 depicts the variation of the tracer gas concentration as a function of time. When the opening is sealed, it is possible to evaluate the air leakage rate of the house, using the tracer gas method : the measured value is 0.04 air change/hour ; this value is very low in accordance with the airtightness of the house (see 3.1). By the same way, the ventilation air change is calculated during the test period.

Results show that air change is 0.21 air change/hour taking into account the air leakage.

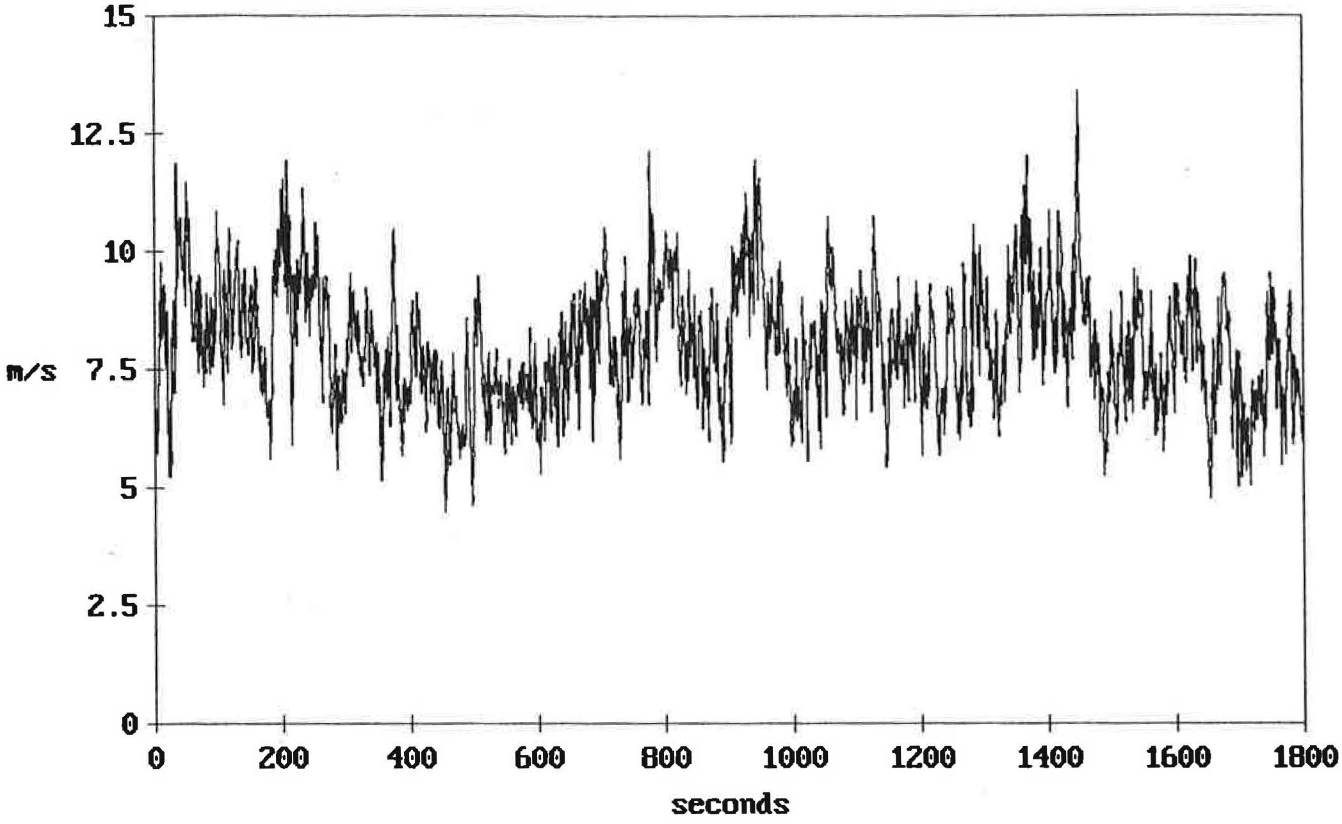


Fig. 7 : *Wind velocity at the top of the house*

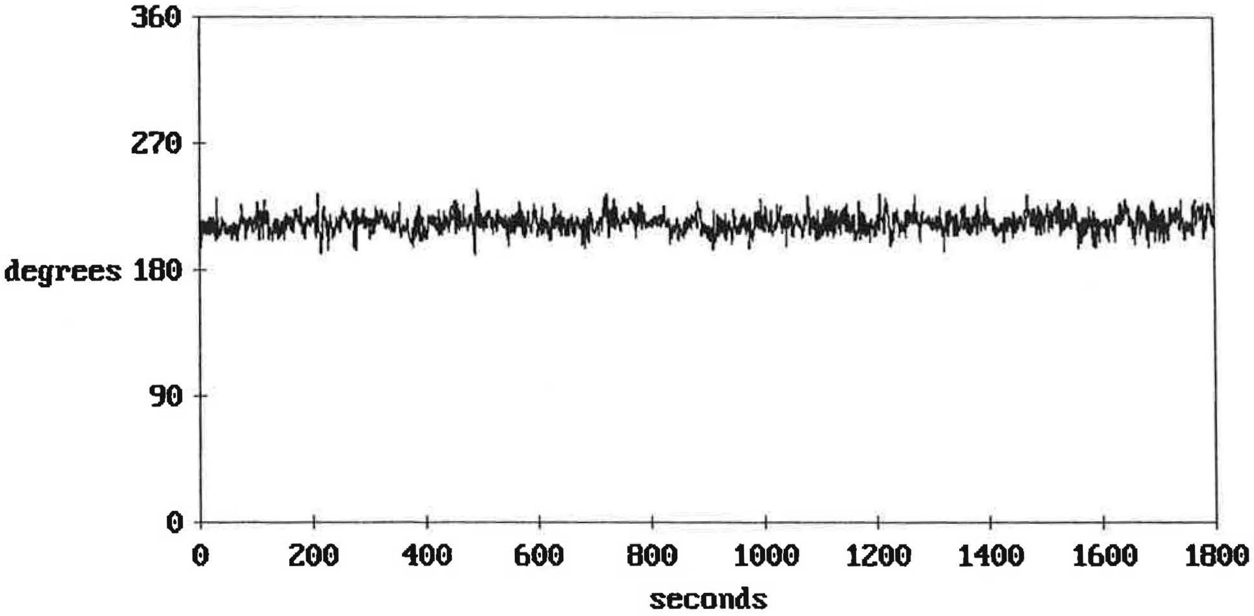


Fig. 8 : *Direction of wind*

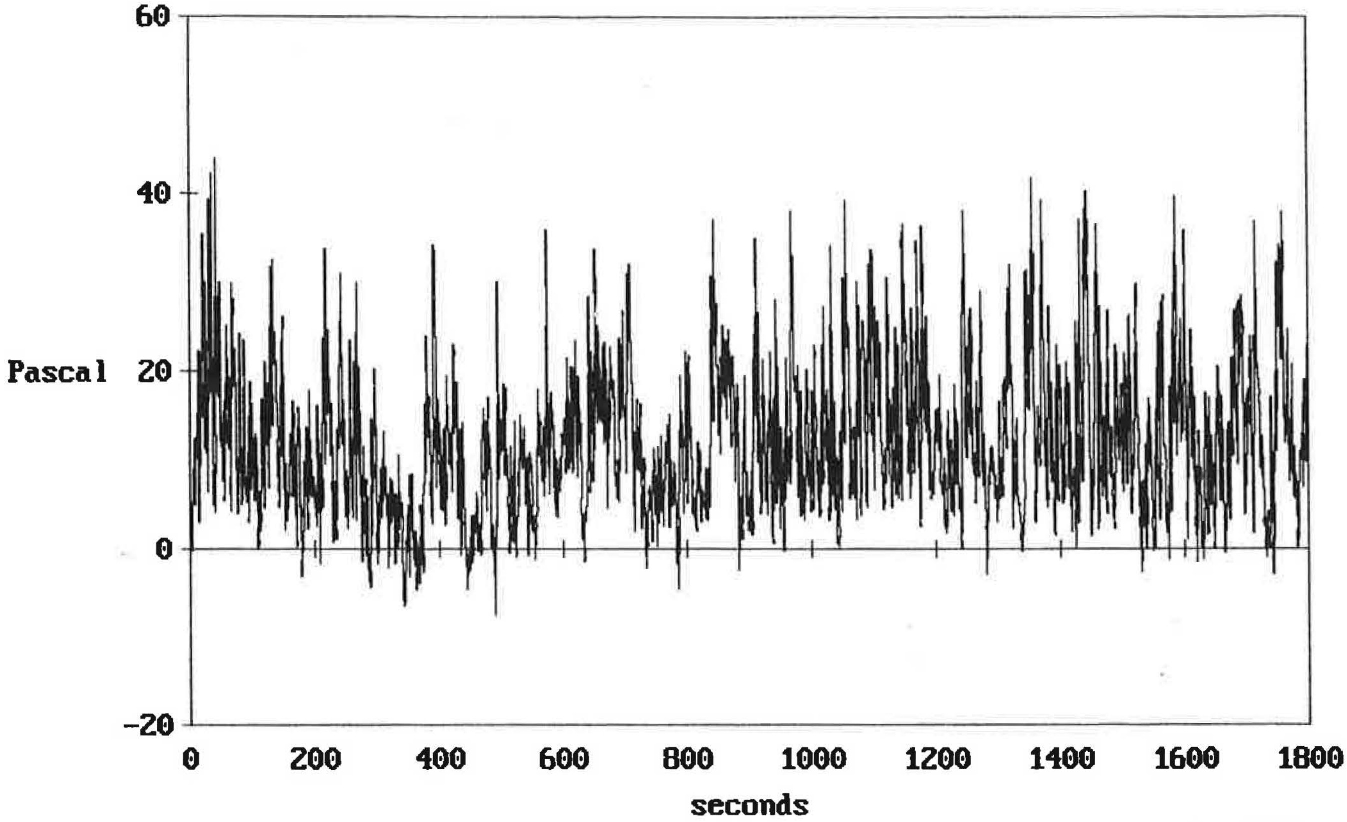


Fig. 9 : *Dynamic pressure at the air inlet*

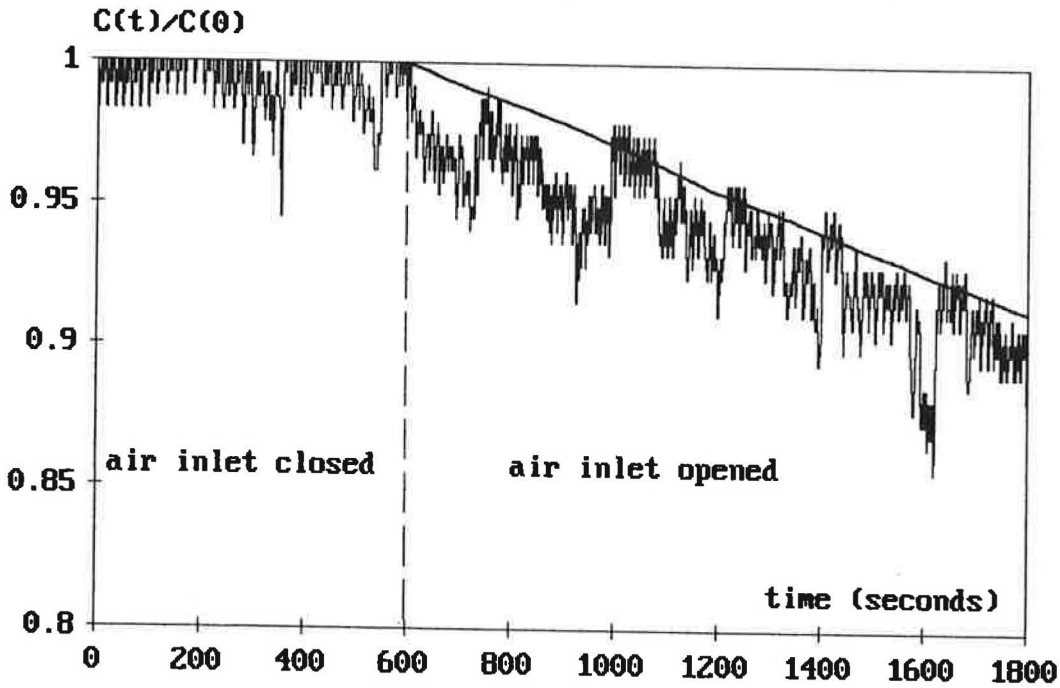


Fig. 10 : *Change in the measured concentration as a function of time*

The figure 11 depicts the variation during two minutes of the inside measurement pressure and the inside pressure calculated using SIREN2 computer code : simulation and measurement results are in close agrement.

The values of gas concentration which were calculated using computer code are plotted in figure 10 : the calculated values are slightly higher than measured values.

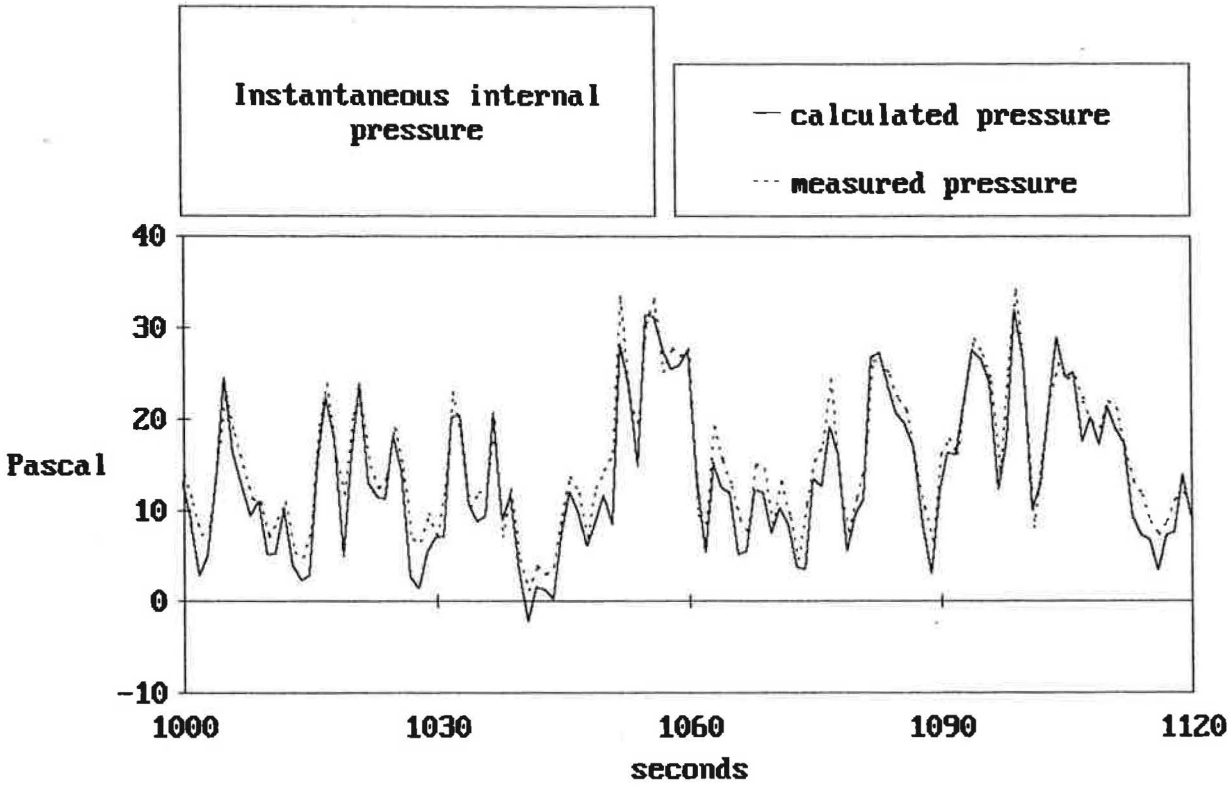


Fig. 11 :

CONCLUSION

Due to the fact that the phenomena governing the air transfers in a building are not linear, the treatment of wind fluctuations results in discrepancies with respect to calculations made when using an average wind pressure value.

Simulation results show the need to take temporal wind fluctuations into account as well as air compressibility for evaluating the air change in a flat with air passages mainly located on one façade.

The wind turbulence can also result in reverse flow occuring in ventilation ducts when they are connected to several floors. Further research will be devoted to studying this problem by incorporating the influence of the mechanical inertia of the air mass present in the pipe.

In order to ascertain the simulation results, an experimental study has been undertaken. The first experimental results are in agrement. More research work is still needed in order to study other ventilation systems configurations.

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ACKNOWLEDGEMENTS

The authors whish to express theirs thanks to R. MOUNAJED who developped computer model.

Participation of A.F.M.E., France, to research support is gratefully acknowledged.