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Paper 14

EFFECT OF WIND PRESSURE FLUCTUATIONS ON AIR MOVEMENTS INSIDE BUILDINGS

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ABSTRACT

An appropriate way to identify the most efficient ventilation systems and improve their design is to use design codes for ventilation rates.

These rates are strongly influenced by spatial and temporal fluctuations in wind pressure on the façade and roof. The influence of the effects of wind on ventilation was studied using a 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 analyzed using a design code. The effect of wind fluctuations on the quality of ventilation is evaluated using the concentration of a polluting agent as an indicator.

Flow rates measurements have been undertaken in an experimental house near Nantes, in order to allow comparison with computer results. The measurement methodology is described and first experimental results are given in this paper.

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 façade, 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 wind fluctuations was studied at the C.S.T.B. 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 under way using flow rates measurements in an experimental rotating house at Bouin (near Nantes). The measurement methodology is described and first experimental results are given.

2 – NUMERICAL STUDY

2.1 – Modelling

The SIREN 2 code was used (see figure 1) to evaluate the air movement between zones within the same building under given temperature and wind pressure conditions and for ventilation installations and buildings with given characteristics [3]. The pressure fields are determined (see figure 2) by measurements in a boundary layer wind tunnel on a 1/150 scale model [4].

For each zone i, the mass balance, assuming isentropic transformation yields:

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

Vi : volume of the zone i
Ti : temperature in zone i
Pi : pressure in zone i
γ : ratio of specific heat at constant pressure to that at constant volume (for air, $\gamma = 1.4$)
r : gas constant (for air, r = 287 J/kg K)
Qi : mass flow rate exchanged between zone i and other zones. It can be expressed as follows :

$$Qi = \sum_j (qij - qji)$$

The index j runs from 0 (outside air) to the number N of zones, but is different of i.

qij : mass flow rate from zone i to zone j. It depends on pressure difference between zones i and j (qij = f(Pi,Pj)).

The differential equations system is solved using Levenberg-Marquardt algorithm (minimimum of the sum of the squares of functions).

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 i.e. the carbon dioxide concentration was used. Two cases were considered [5] :

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 façades, the communication door is open and there is a constant flow of pollutant in room n° 1.

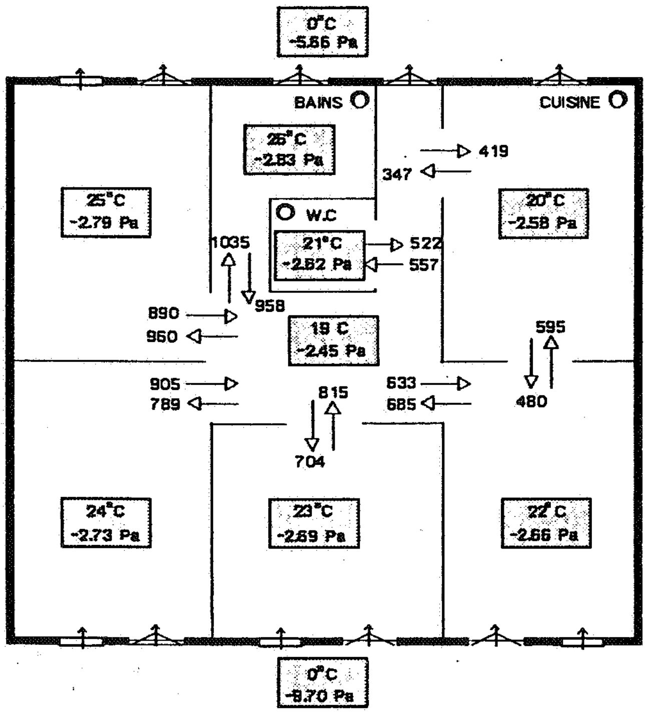


Figure 1 :
Computed flow rates (in kg/h) in a dwelling with mechanical ventilation

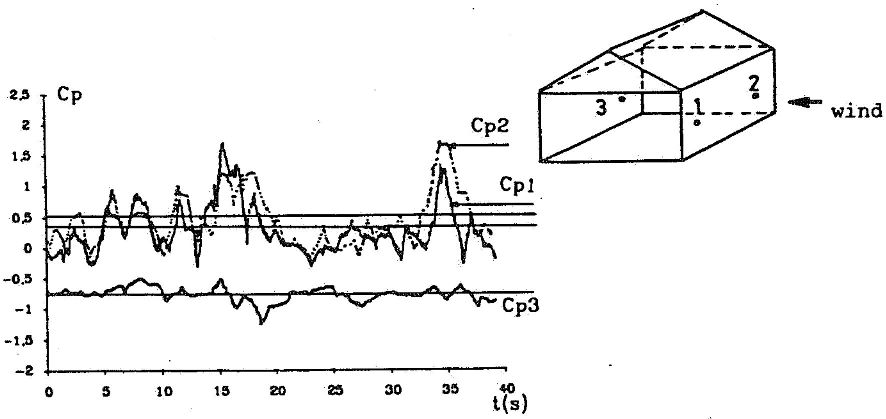
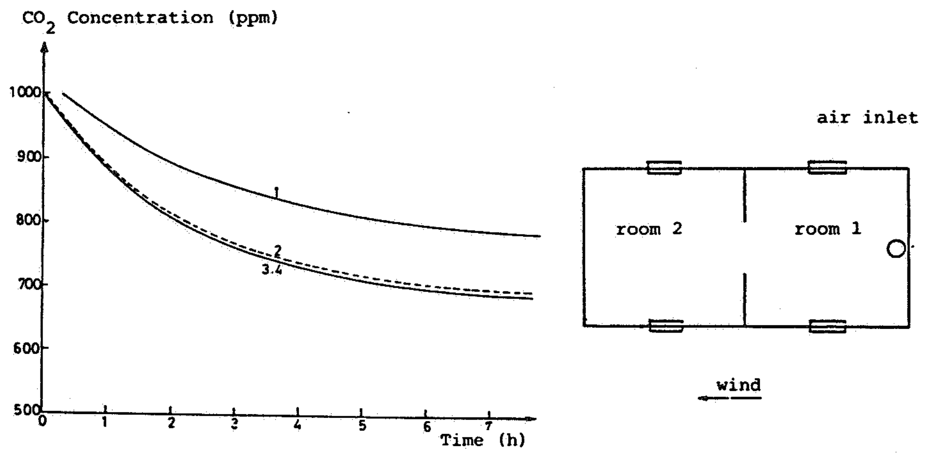


Figure 2 : Examples of wind pressure spatial and temporal fluctuations



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

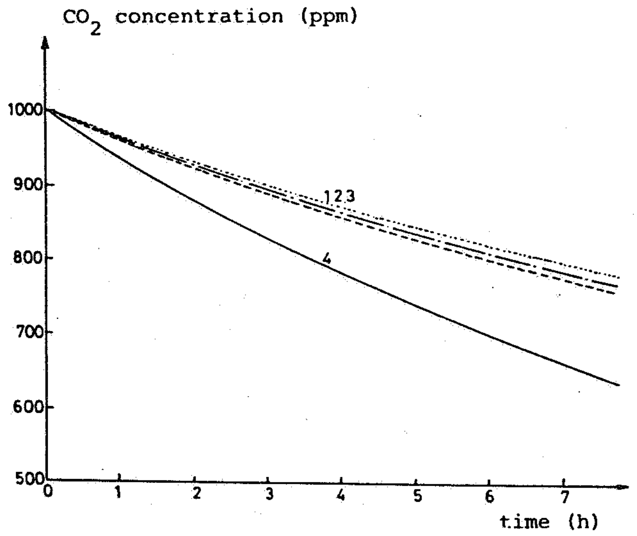
Figure 3 :
Changes in the carbon dioxide concentration in room n° 2 as a function of time. Wind is parallel to the façades and communication door open

The results show that, unlike the air compressibility, the effect of temporal wind fluctuations cannot be ignored. This effect on the ventilation is particularly important when the wind is parallel to the main façades (see figure 3) ; ignoring this can produce errors of up to 35 % in the CO_2 concentration. The effect of wind pressure spatial fluctuations was also investigated and proved to be lower (10 % instead 35 %) than the temporal fluctuations effect.

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 façade passes through a free section of 200 cm^2, while the opening in the opposite façade, corresponding to defective airtightness, is only 10 cm^2. It is assumed that no carbon dioxide 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 observed that, unlike the previous example, the hypothesis of air compressibility is a relevant factor. This is explained by the large difference between the sections of the two openings (ratio of 1 to 20).



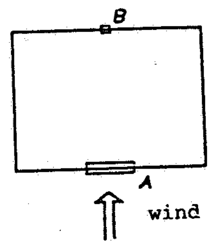


Figure 4 : Carbon dioxide concentration versus time
(refer to figure 3 for meaning of hypotheses 1, 2, 3 and 4)

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 stack ventilation ducts [6] was also investigated. Emissions of carbon dioxide 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 results show that taking the wind fluctuations into account considerably modifies the instant flow rates and may explain the reverse air flow on the top floor for high values of the network head loss (figure 5).

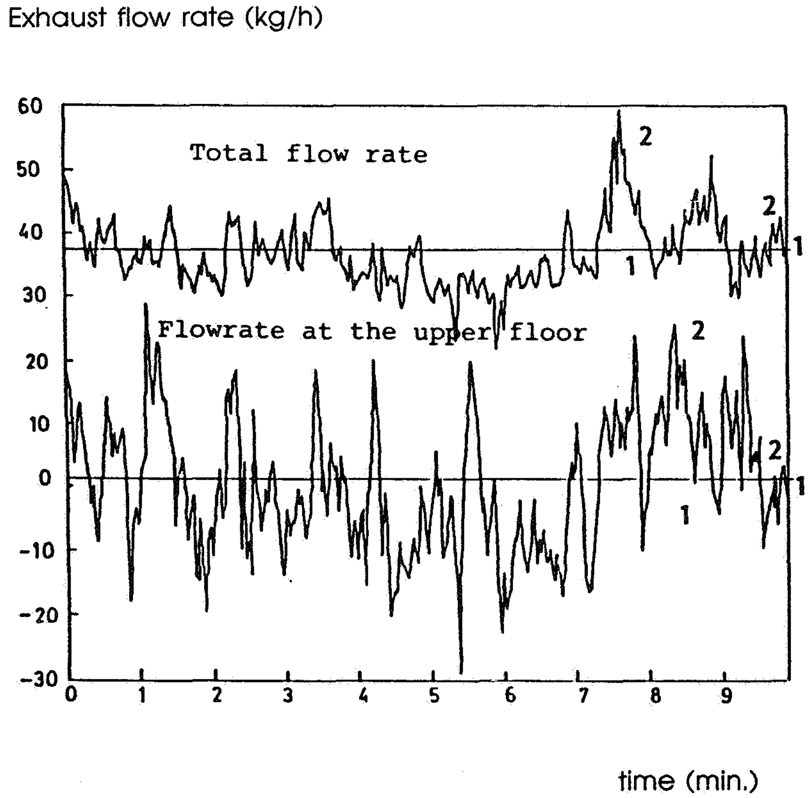


Figure 5 : Computed flow rates in a shunt duct

1 : flow rates are calculated using time averaged wind pressure
2 : flow rates 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 flow rate.

3.1 – Experimental house

The experimental house is located at BOUIN, on the atlantic coast, in a windy area. It is a single-storey house (9m x 5m x 4m) ; the roof is pitched at 30 degrees (see figure 6). The BOUIN experimental house is a rotating house which can be turned toward a given direction of wind.

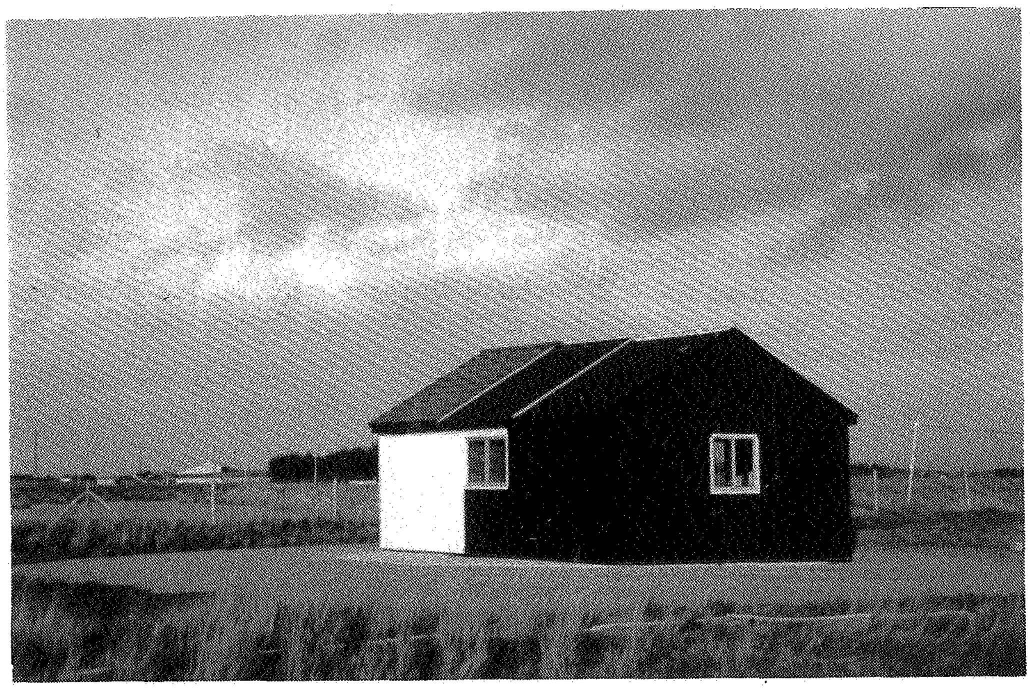


Figure 6 : View of the BOUIN experimental house

Particular attention was paid to improve the building envelope airtightness. The measured air leakage value proved to be equivalent to 5 cm^2.

3.2 – Instrumentation

Pressure tapping points are distributed along the outside surface of the walls, and close to the air inlet and outlet orifices. The speed and direction of the wind are recorded together with other measurements. The ventilation rate is measured using the tracer gas method. This instrumentation is completed by a fast response (40 Hz) measuring equipment [7], designed to instantaneously record the air flow entering or leaving the external openings.

3.3 - Tests

Single sided ventilation through one external opening of the house has been studied [8]. Two openings were tested : sharp-edged slots with dimensions of 40cm x 2.5cm or 40cm x 5cm. The opening was located either windward or leeward, at 2m above the ground level.

Tests were carried out in order to measure air change inside the house. The test procedure is as follows :

- orientation of the experimental house
- sealing of the opening
- tracer gas injection
- mixing of gas inside the volume during 10 minutes period, using fans
- data logging : the acquisition frequency is 5 Hz, the decay test period (opening unsealed) is 20 minutes.

3.4 - Results

Tests results for differents configurations are given in following table.

test	opening		wind		air change rate
	area (cm^2)	location	mean (m/s)	standard deviation (m/s)	(ach)
1	100	windward	7.7	1.2	0.25
2	100	leeward	10.2	1.5	0.69
3	200	windward	5.8	1.15	0.44
4	200	leeward	5.8	1.1	0.24

Air compressibility and wind fluctuations assumptions are required to explain the measured air change values.

Dynamic pressure at the opening and wind velocity and direction are shown, for example, in figures 7, 8 and 9. The data refer to the test 1.

Figure 10 depicts for the test 1 the variation of the measured inside pressure (relative to outside static pressure) and the inside pressure calculated using SIREN2 computer code.

For this same test, the variation of the tracer gas concentration as a function of time is shown in figure 11 : measured and calculated values are plotted in the same graph. In this case, predicted and measured results are in close agreement.

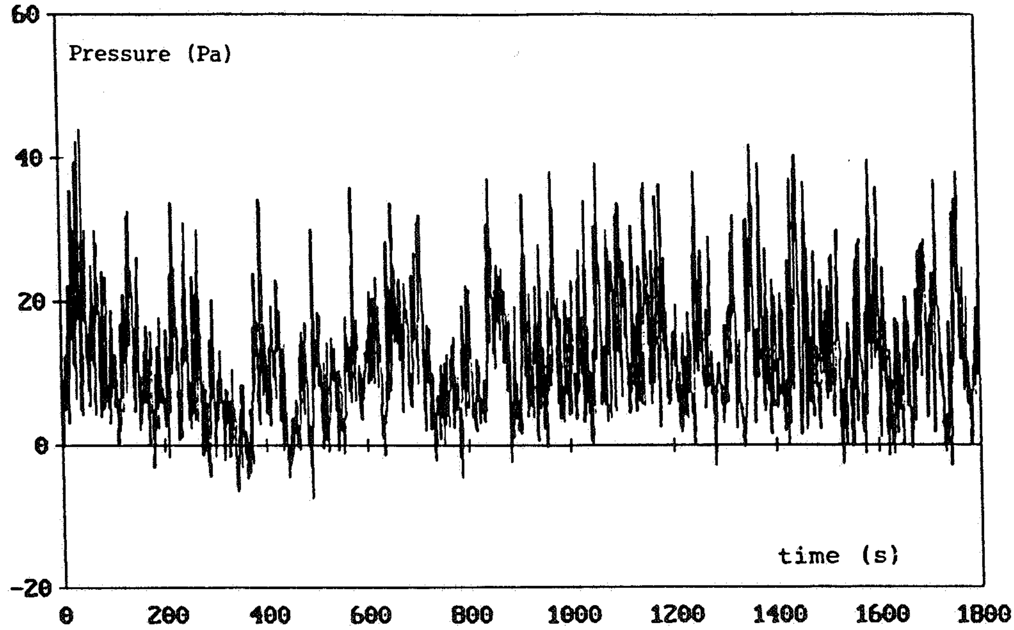


Figure 7 : Dynamic pressure at the opening

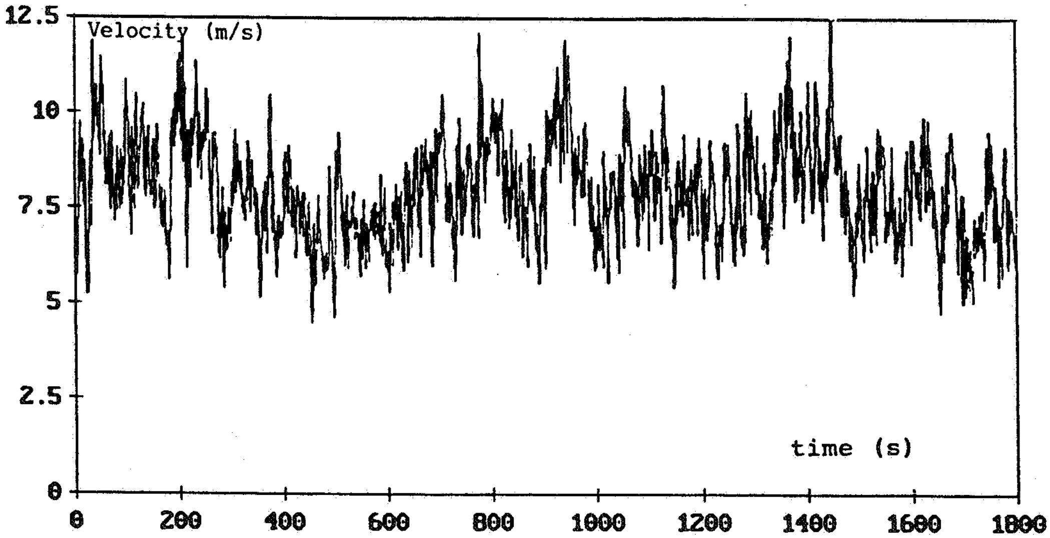


Figure 8 : Wind velocity at the top of the house

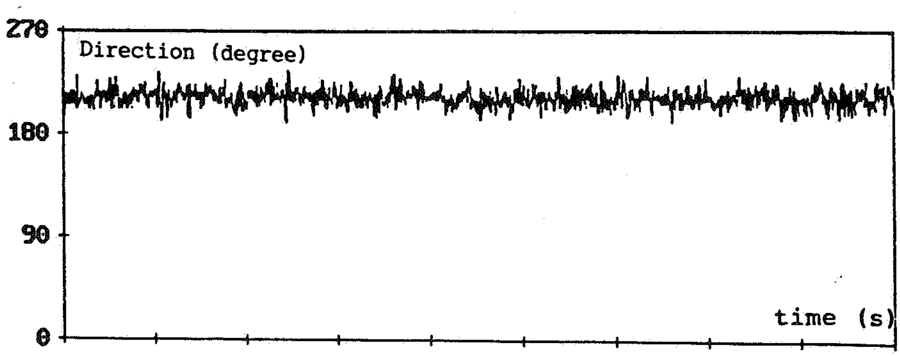


Figure 9 : Wind direction at the top of the house

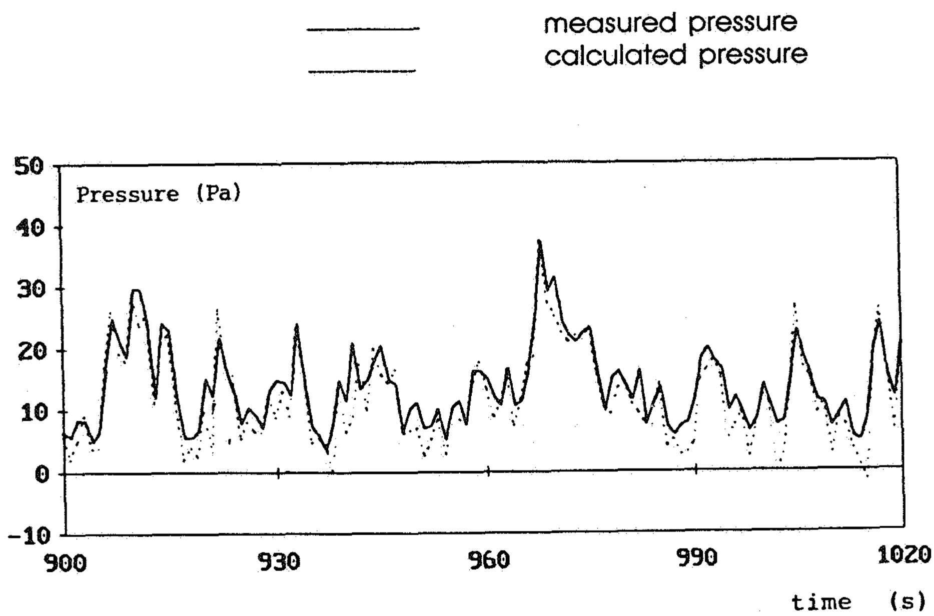


Figure 10 : Inside pressure versus time

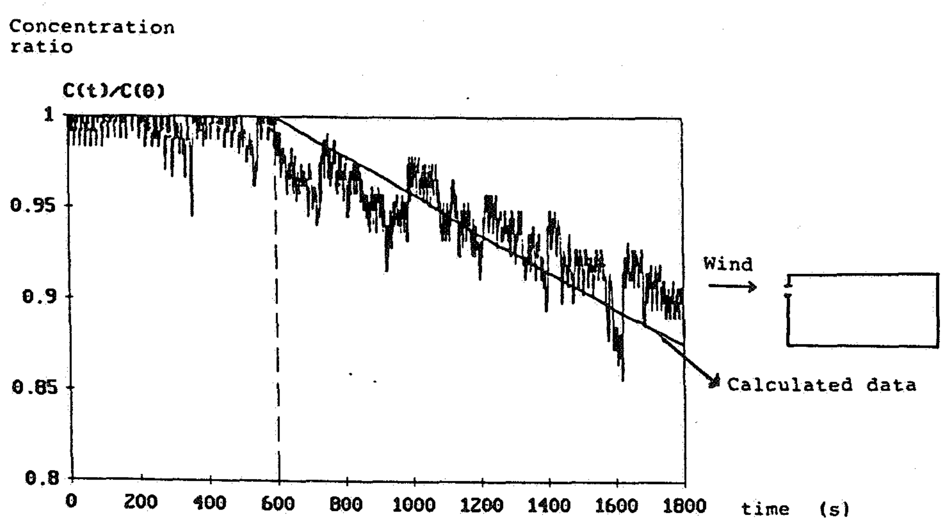


Figure 11 : Tracer gas concentration versus time
(measured and calculated data)

For the other tests, the agreement between measured concentrations and those derived from calculated flow rates is not as well. The predicted decrease in concentration is generally greater than the measured decrease. The discrepancy might be explain because at the same time air flows go through the opening into opposite directions ("inlet-outlet openings"), assuming wind pressure spatial fluctuations distributed along the opening. This flow pattern is not taken into account in the model.

4 - CONCLUSIONS

Due to non linearity of phenomena governing the air transfers in a building, the assumption of wind fluctuations results in discrepancies with respect to calculations made using an average wind pressure value.

Calculations show the necessity 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 linked to different 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.

The first experimental results refer to single sided ventilation when the external opening is windward or leeward : the renewall rates are about 0.2 to 0.4 ach. These values are not, in all the cases, in agreement with values predicted by the model : the differences might be due to pressure and concentration measurement method or computer model which does not take bi-directional flow through the opening into account or different behaviour of the air inlet according to its location is either windward or leeward.

However, very few tests have been analysed and more research work is still needed in order to ascertain results. The experimental research programme is carried out to study another cases of wind-induced ventilation.

ACKNOWLEDGEMENTS

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Discussion

Paper 14

Earle Perera (BRE, UK)

Is compressibility the real factor which influences ventilation in an enclosure with a single opening? Would not effects like two-way flow or turbulence effects (similar to the work of N.Potter, as reported in ASHRAE Transactions) be the factor?

D.Bienfait (CSTC, France)

2 way flow over openings has much more effect than the air compressibility. Our research work is only concerned with small apertures (less than 100 cm²) for which two-way flow is likely to be less important. At the moment there is rather good agreement between measurements and the air compressibility explanation, but it is obviously necessary to investigate more thoroughly the question you have raised.

W.F.De Gids (TNO, Netherlands)

The air leakage of the dwellings were expressed as L_{50} value. What are the n_{50} values. So the air change rates measured at 50 Pa during pressurisation test.

$L_{50} \approx 1200 \mathrm{m}^3/\mathrm{h} \hat{=} n_{50} of ? ACH$

D.Bienfait (CSTC, France)

Mean values are: multifamily buildings: n_{50} # 5 ach, single family buildings: n_{50} # 2 ach. It should be stressed that these values were measured some years ago. Since that time new building codes of practice have been issued and hopefully in the future the n_{50} values will be less important.