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(Title)

EXPERIMENTAL STUDY OF CRACK FLOW WITH VARYING PRESSURE DIFFERENTIALS

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Experimental Study of Crack Flow with Varying Pressure Differentials

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Synopsis

Existing experimental techniques for calculating air flow through building cracks are usually based upon relationships derived from experimental studies employing relatively simple procedures. Typically, a fixed pressure difference, ΔP, is established across the crack of interest and then the air flow Q through the crack is determined. Most crack flow equations take the pressure differential ΔP to be steady-state. In reality, the wind forces which generate much of the driving pressures represent highly fluctuating signals. A basic problem is to know what effect a fluctuating ΔP has on the overall air flow through building cracks. The basic aim of this study was to determine the impact of these fluctuating pressures on crack flow equations. Experimental techniques generated sinusoidal pressure fluctuations across a range of fabricated, straight-through cracks, ranging from 1 to 5 mm in thickness. Fluctuation frequencies from 0.5 to 2.5 Hz were used in the investigations. The results suggest that the average flow under conditions of fluctuating pressure differentials does not differ significantly from the flow which would occur if the mean pressure differential were imposed. This implies that the instantaneous flow at any fluctuating value of the pressure differential is that corresponding to the pressure differential on the steady-state flow-pressure curve.

1 Introduction

Equations for calculating the air flow Q through a building crack experiencing a steady pressure difference across it of ΔP are normally presented in either a power law or quadratic format:

$$Q = a\,(\Delta P)^n \qquad (1)$$

$$\Delta P = AQ^2 + BQ \qquad (2)$$

where a, n, A and B are experimental coefficients. Examples of this type of approach can be found in the works of Baker *et al.* [1], Fleury *et al.* [2] and Yakubu and Sharples [3]. Potter [4] investigated the possible errors produced by the use of a 'steady-state' crack flow model when the driving pressure differences are actually fluctuating. A series of field measurements were made on a single room with windows in opposite walls, using a flow measuring device and tracer gas analysis. Significant errors were found between the ventilation rates predicted by the steady-state method and those measured in the room. Laboratory studies of ventilation generated by fluctuating pressure differentials were made by Sahin *et al.* [5] on a range of orifice and cylindrical tube shapes. This work did not deal explicitly with building crack geometries, and nor did a study by Rao and Haghighat [6], which used a bundle of straws as their specific flow opening. They developed a fluctuating air flow model which made use of spectral analysis and statistical linearisation techniques and obtained good agreement between the model and their experimental results. A more detailed discussion of the model is given by Haghighat *et al.* [7]. Although some recent work has been done on fluctuating flows through large openings (see Haghighat *et al.* [8]) there is still a lack of fundamental experimental data for fluctuating flows through building cracks. Kronvall [9] has suggested that for cracks exposed to, say, a sinusoidal fluctuating pressure difference [$\Delta P \sin(\omega t)$] then equation (1) could be modified to the form

$$Q = a[\Delta P \sin(\omega t)]^n \tag{3}$$

Theories such as that expressed by equation (3) had not been tested experimentally. The main aim of this project was to develop a measurement programme to obtain fluctuating flow and pressure data for building cracks.

2 Method

For the experimental measurements the basic requirements were for a means of generating fluctuating controllable air flows, a crack rig across which fluctuating pressure differences could be produced and instrumentation capable of measuring the range of flows and pressures to be observed in the experiments. The cracks used in the study were mounted in one side of a plenum chamber measuring 1x1x1m. The opposite side of the plenum was connected to a length of ductwork which housed a Furness Controls Laminar Flowmeter FCO96-2000L. A laminar flow device was chosen for measuring flow because of its robustness, high turn-down ratio and ability to measure reversing flows. Discussions with Furness Controls alleviated concerns about the ability of laminar flow devices to follow accurately the fluctuations in the flows. The pressure drops across the laminar flow device and the cracks were monitored by highly sensitive Furness Controls FCO12 digital micromanometers. Fluctuations in the air flow were produced by incorporating in the ductwork a rotatable damper linked to a servo drive motor which, in turn, was driven by a Feedback FG601 signal generator. Frequency fluctuations between 0.5 Hz and 2.5 Hz could be obtained with this arrangement. The duct-plenum was connected to four variable speed fans, which were arranged so as to allow the flow direction to be reversed for some of the experiments i.e. pressurisation or depressurisation of the plenum. The general layout is shown in Figure 1.

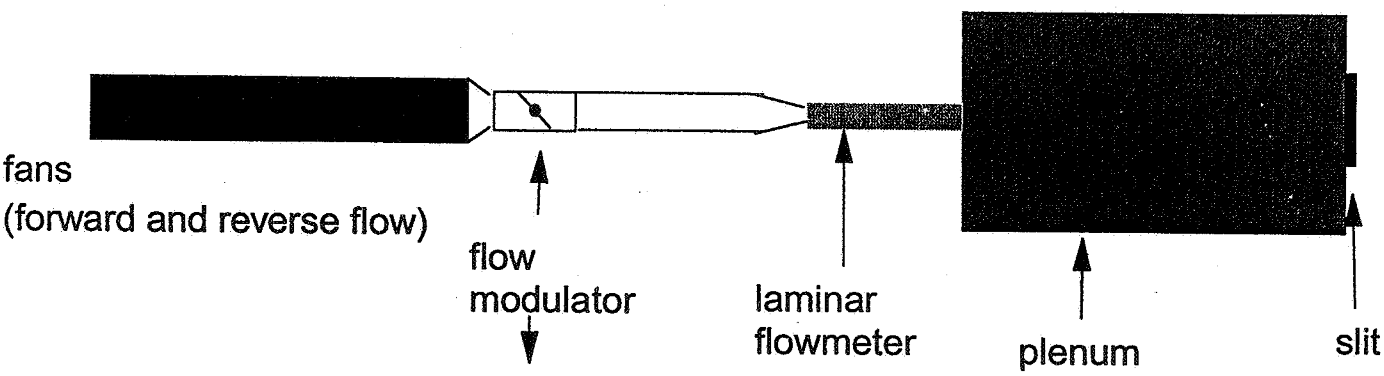

Figure 1 Layout of test rig for unidirectional flow

3 Experimental Measurements

Measurements were made on a range of crack sizes and geometries. Each crack was fabricated from Perspex, and was 500 mm wide and 50 mm deep. For simple parallel sided cracks the heights investigated were 1, 2, 3 and 5 mm. Figure 2 show the geometry of the cracks.

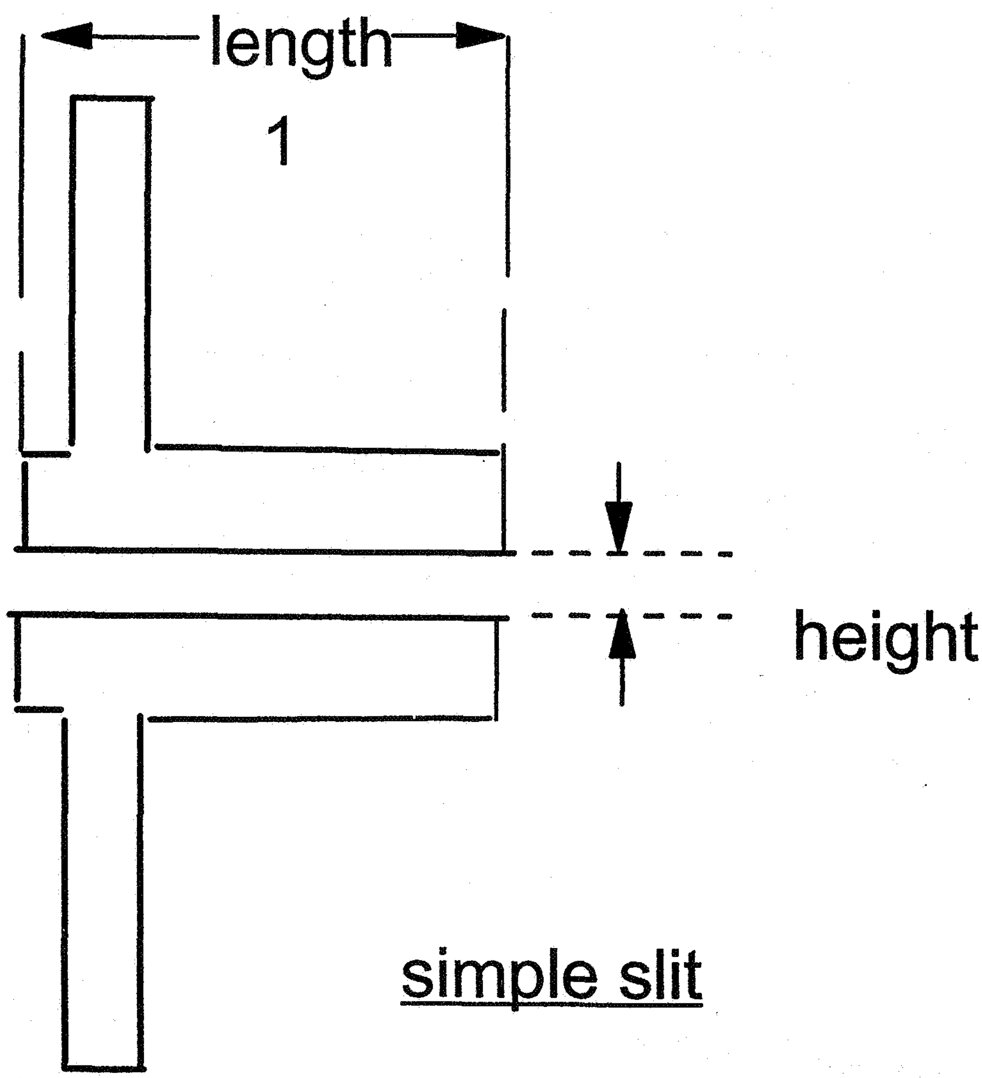

Figure 2 Geometry of simple straight-through crack

Voltage signals from the micromanometers were collected by two Pico analogue to digital converters and stored on computer files. Each measurement record consisted of a 20 second duration of data collection. Four thousand measurements per channel were obtained, and so the sampling interval was 5 milliseconds. It appeared from the measurements that in addition to the fluctuations imposed by movement of the flap valve there were significant fluctuations at higher frequencies. There were indications of phase lags of pressure behind flow, at the imposed frequency, but the secondary signals and the non-sinusoidal form of the wave were sufficient to make any attempt to scale the amplitudes of the oscillations to allow phase relationships to be examined very imprecise. In order to examine such relationships a computer program 'Spectrum', available from Hensa Micros Archive, and originating from the American National Institute of Standards and Technology, was used (Hess[10]). The original purpose of the program was to observe the phase separation due to small disturbances in a flow system some distance downstream of the point where they were generated, and derive the phase lag despite significant background noise. Consequently the program is ideally suited to the present purpose. In use on reasonably extensive records of pressure fluctuations, the program can derive from simultaneous records of two outputs: amplitude spectra for both channels; power spectra for both channels and cross spectra and phase angle spectra.

4 Experimental Results of Laboratory Fluctuating Crack Flow Measurements

Experiments were carried out with flow both into, and out of, the plenum chamber through the slit, and for several slit sizes. The data were transferred to Lotus 123 spreadsheets, and the use of the 'Spectrum' software allowed phase lag corrections to the flow and pressure data to be applied. The time mean flows were obtained and compared with the pressure-flow curves for steady state operation. Figures 3 and 4 show, for 1 and 5 mm cracks respectively, the results for the time-mean flows imposed on the steady-state calibration curves.

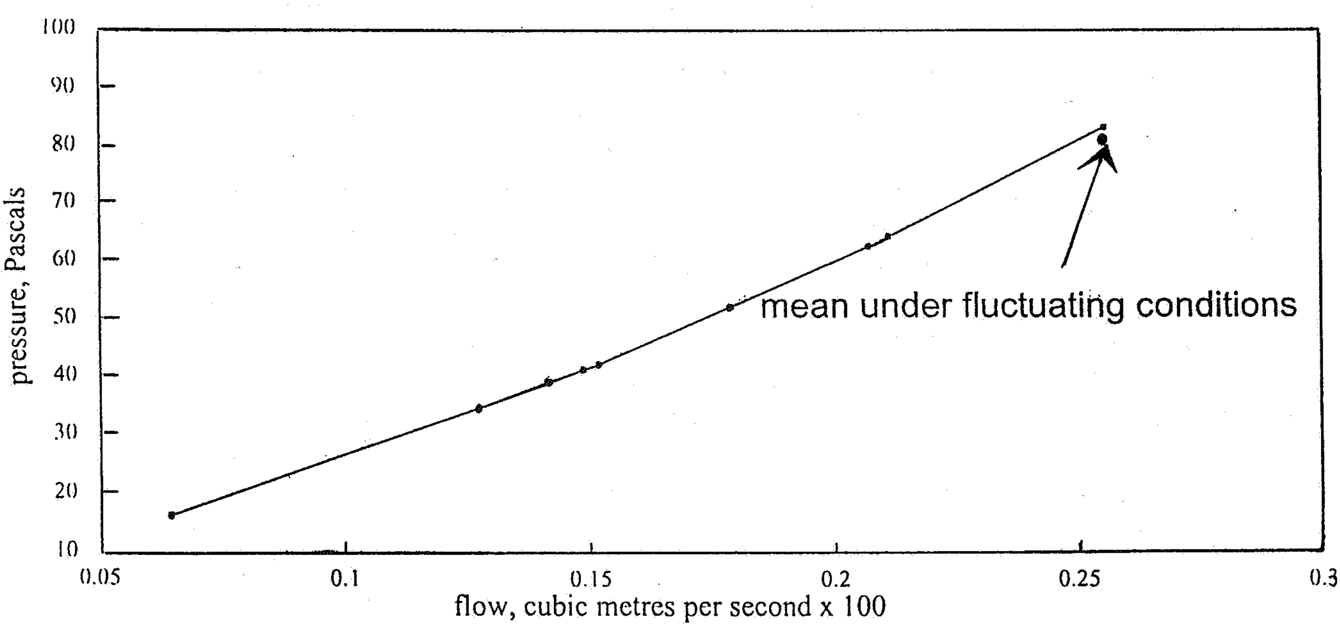

Figure 3 Steady state and fluctuating flow values for a 1 mm slit

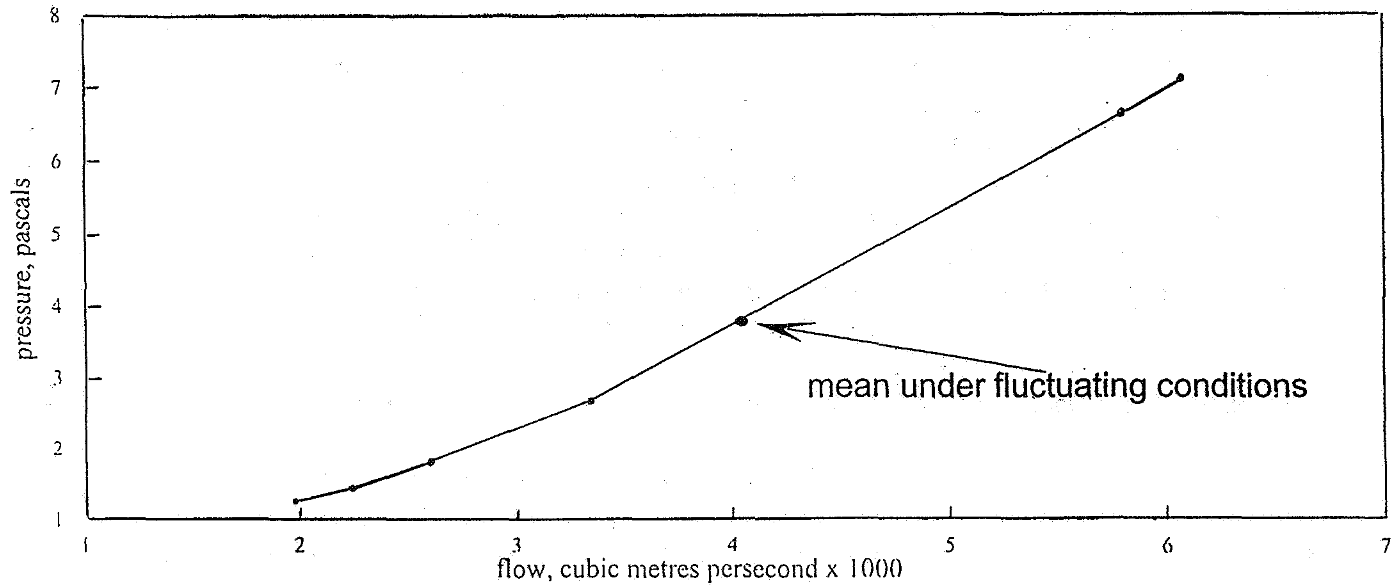

Figure 4 Steady state and fluctuating flow values for a 5 mm slit

For flow in either direction and for all slits, the time average flow under fluctuating conditions was found to be very close to the steady-state calibration curve. In order to examine the possibility that the phase lag was related to capacitative effects within the system, a series of experiments were carried out using a much smaller plenum chamber, with total volume $0.0156 m^3$ (compared to a plenum volume of $1.0\ m^3$ in the original experiments). These experiments also indicated close agreement between steady-state flow and time-average of fluctuating flow. A further experiment was carried out to determine whether turbulence could influence the flow. A centrifugal fan was mounted in a second $1 m^3$ chamber and the open side of the chamber was moved close to the face of the other plenum in which a crack was mounted. The fan generated turbulence, and the flow through the crack was measured with constant suction, but with this secondary fan on and off. The flows were the same for the fan on and off within the limits of experimental error, and it is concluded that the large scale turbulence did not affect the flow through the smooth crack significantly. The results have shown that the average flow under conditions of fluctuating pressure differentials does not differ significantly from the flow which would occur if the mean pressure differential were imposed. This implies that the instantaneous flow at any fluctuating value of the pressure differential is that corresponding to the pressure differential on the steady state flow-pressure curve.

5 Experimental Results of Fabricated Crack Mounted in Real Window

A separate investigation was carried out to obtain simultaneous records of the pressure differential between the pressure adjacent to a slit mounted in a real window and the pressure in the laboratory, and the flow through the slit. The 2 mm, 500 mm wide crack was attached to a small plenum and fixed to a sheet of marine plywood which was then fixed into the space left by an open window, as shown schematically in Figure 5. The window was located on the 18th floor of a 19 storey tower block. In these experiments the low flow range of the flowmeter was used, i.e. the pressure tappings nearest the ends of the plates. As the laboratory was on the eighteenth floor of a building in one of the higher parts of Sheffield, a strong wind with minimal effect due to other buildings was readily available. To obtain results requiring analysis in depth it would have been necessary to seal all unspecified apertures in the laboratory and carry out confirmation that these were all sealed by pressure testing. The time allowed did not permit this, and consequently the project was limited to definition of an experimental layout suitable for future work, and confirmation that there was no obvious deviation from the results obtained with the earlier laboratory test rigs described earlier. Some apparent divergence in some of the data points was assumed to be due to either (i) activity in the building leading to pressurisation or depressurisation of the room via cracks around the doors (ii) switches in wind direction leading to a pressure change by enhanced or decreased ventilation via cracks in the wall at right angles to the wall in which the crack was mounted (the laboratory was at the corner of the building) (iii) gusting leading to flexing of the windows remote from the test crack and consequent volume changes not reflected fully in the pressure differential across the crack.

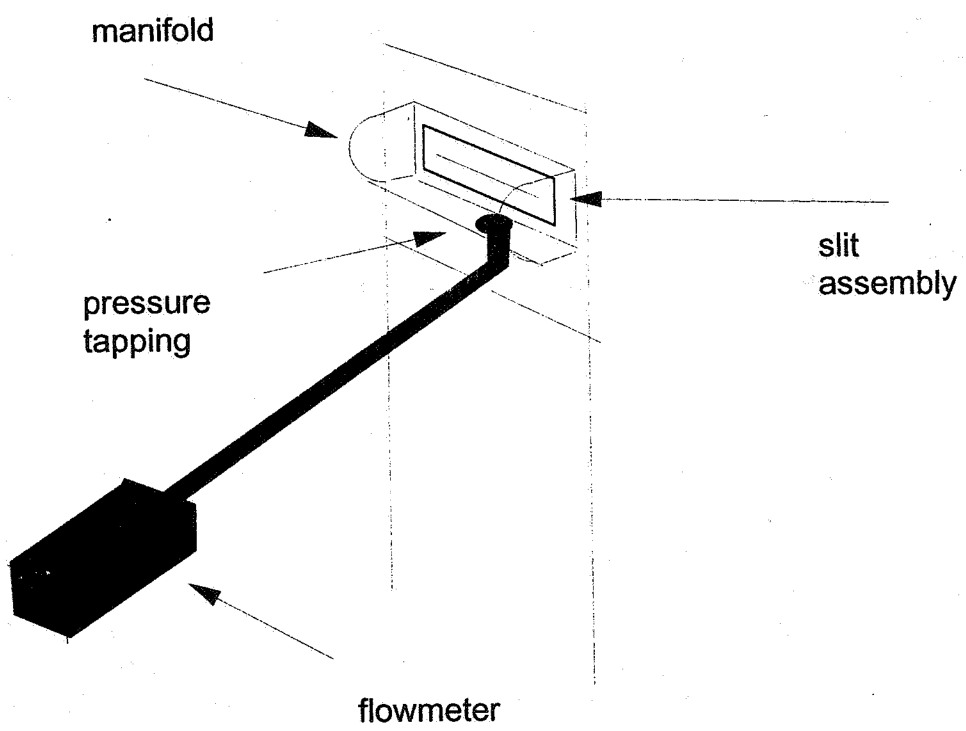

Figure 5 Crack flow arrangement for open window measurements

6 Conclusions

This investigation has been very specifically aimed at the definition of fluctuating pressure-flow relationships for a crack in the wall of a building. It has shown that the flow through such a crack is not materially affected by fluctuations in the local pressure differential, and that the flow over a period of time under conditions of fluctuating flow can be satisfactorily represented by the flow for the equivalent time-average pressure differential.

This conclusion contrasts with the observations by Potter [4], who found that room exchange rates were affected markedly by fluctuating pressures. His measurements were made with nitrous oxide tracer concentration decay as the monitor of exchange, and although he remarks that there are considerable potential uncertainties in the results, there are also potential reasons why his observations are valid reflections of the divergence between the volume exchange implied by the static flow calibration of the leaks and that implied by the decay in nitrous oxide concentration. Firstly, he notes that the spurious leaks were sealed with plastic sheeting: secondly, homogeneity within the room must inevitably take some considerable time when tracer-free air is admitted. The comment about plastic sheeting arises because such sheets could be flexible, and depending on the degree of flexibility and the direction in which the leakage path it closes lies, can oppose or support transfer of air through the test leak.

The delay in mixing can be discussed as a generality for any system: the air entering has momentum, and may indeed be hotter or colder than the air in the room and rise or fall - but it will retain some degree of unmixedness for some period, and will move away from the point of entry. If reverse flow occurs, the air leaving will be undiluted by the air entering in the previous half-cycle (and there is no reason to suppose that a stream of progressively mixed air can build up representing the mixing history over several cycles). The loss of nitrous oxide could well, therefore, exceed the rate predicted for perfect mixing. A furthei complication could arise if the air entering were cooler than the air inside: in this case warming and expansion lags may occur. If the admitted air is approximated as a series of expanding volumes then this could lead to a rising internal pressure which eventually reaches steady state, but could lead to faster exchange whilst doing so.

Overall, the results from the project are reassuring for air flow modellers. The pressure fluctuations which are known to occur in the natural environment need not be considered as a potential source of error when steady-state crack flow algorithms are used in models. It appears that the relatively high resistance to flow offered by narrow cracks effectively damps out the impact of the fluctuations on the observed flows, allowing time-averaged mean values (i.e. steady-state) to be used. The modelled and observed fluctuating flows through large openings obviously represent a physically very different flow environment to that of narrow cracks. It would be an area of future research interest to investigate how and under what geometric and physical conditions the transitions take place for fluctuating flows from the insensitive small cracks to the sensitive large openings.

7 References

[1] Baker P H, Sharples S and Ward I C,
Air flow through cracks.
Building and Environment, **22** (4), 293-304, 1987

[2] Fleury B A, Gadilhe A Y, Niard P and Chazelas J L,
Air flow through building slits and components.
Proc 11th AIVC Conference, 389-399, Beligrate, Italy, 18-21 September, 1990

[3] Yakubu G S and Sharples S,
Air flow through modulated louvre systems.
Building Services Engineering Research & Technology, **12** (4), 151-155, 1991

[4] Potter I N,
Effect of fluctuating wind pressures on natural ventilation rates.
ASHRAE Transactions, **85,** part 2, 445-457, 1979

[5] Sahin B, Clark C, Reynolds A J and Wakelin R,
Ventilation generated by a fluctuating pressure differential.
Proc 9th AIVC Conference, 81-104, Gent, Belgium, 12-15 September, 1988

[6] Rao J and Haghighat F,
Wind induced fluctuating airflow in buildings.
Proc 12th AIVC Conference, 111-121, Ottawa, Canada, 24-27 September, 1991

[7] Haghighat F, Rao J and Fazio P,
The influence of turbulent wind on air change rates - a modelling approach.
Building and Environment, **26** (2), 95-109, 1991

[8] Haghighat F, Rao J and Riberon J,
Modelling fluctuating airflow through large openings.
Proc 13th AIVC Conference, 77-85, Nice, France, 15-18 September, 1992

[9] Kronvall J,
Air flows in building components.
Lund Institute of Technology, Report TVBH-1002, 1980

[10] Hess D E, Spectral Analysis on a PC.
Report NISTIR 4733, U.S. Department of Commerce,
National Institute of Standards and Technology, December 1991