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THE VENTILATION CHAMBER OF THE UNIVERSITY OF BASILICATA

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Synopsis

*A new facility for the study of ventilation in buildings has been recently developed at the University of Basilicata (Potenza, Italy). This facility consists in a Controlled Ventilation Chamber (CVC), with an overall size of 2.4*2.4*3.0 m (the length may be extended to 4.2 m). The CVC is divisible in two parts with a connecting door and is equipped with four grilles from which air can be immitted or extracted. A variable speed fan can adjust a flow rate of 0 to 10 ach. Instrumentation includes a flow rate transducer in the ducts, six low speed hot film anemometers in the room, a two-cell infrared gas analyzer for SF_6 and N_2O concentration, and a differential pressure manual meter. Air sampling at different locations is controlled through a pneumatic scanner by a PC which also serves for data collection and elaboration. The CVC will be used both for ventilation frequency and ventilation efficiency measurements. Black-box identification will be adopted as a novel technique to determine the ventilation frequency (under perfect mixing hypothesis) with varying air change rates and tracer gas immission rates.*

List of symbols

$C(t)$	= concentration of tracer gas at time t
n	= ventilation frequency (number of air changes)
t	= time
V	= volume of the room
$\dot{V}(t)$	= air flow rate across the confined space
τ	= 1/n, time constant of the system
ϵ_j	= ventilation efficiency at point j

Subscripts

b	= background
e	= extraction
g	= tracer gas

1. Introduction

The study of air infiltration, mechanical ventilation, and related hygienic problems has recently raised an increasing interest within the research community (see, e g, Sandberg, 1983, Skåret, 1986), and also the public opinion and mass media. In fact, the concern about environmental problems, both outdoors and indoors, has at the moment drawn much of the attention from energy savings problems.

The initiative to build a Controlled Ventilation Chamber (CVC) at the University of Basilicata responds to the need to improve our knowledge about the phenomena of pollutant diffusion and removal by means of forced ventilation devices.

Financing of the project started in november 1988, and the experimental apparatus was fully operating already in spring 1990, after less than 18 months.

The CVC will be used to evaluate, under different testing procedures and ventilation strategies, ventilation efficiency and pollutant removal in the rooms. It will be employed to validate 2-D or 3-D computer models describing the fluid dynamics in a confined space. Moreover, this facility will be used to determine the ventilation frequency using non-conventional data elaboration procedures.

2. The Controlled Ventilation Chamber (CVC)

The Controlled Ventilation Chamber (see Fig. 1) is a small but full size room of 2.4 (height) x 2.4 x 3.0 m. The frame of the chamber is made of steel shapes. Its length (3.0 m) can be increased up to 4.2 m, and a moveable wall can divide the room in two communicating parts, in order to simulate contaminant diffusion from one room to another. One of the 3.2 x 2.4 m wall is made of acrylics, better known with its commercial name "plexiglass", in order to allow visualization of the air flow.

2.1 The ductwork

The ventilation system of the CVC includes a variable speed fan with flow rates ranging from 0 to 160 m^3/h (corresponding to about 10 ach), a ductwork connecting the fan to the CVC, equipped with ball valves, and four grilles for air inlet or outlet.

These grilles are located on the two smaller opposite walls, one close to the ceiling, the other to the ground. On each of them a grille is mounted on which individually orientable vertical fins are located. Width of the grilles is 2.0 m, slightly less than that of the wall, and their height is 0.25 m. Air can be introduced and extracted into or out of the CVC from each of the grilles, realizing different ventilation strategies. At the moment no thermal treatment of the air is provided for.

2.2 Instrumentation

Instrumentation (see Fig. 2) includes:

- an air flow meter
- six hot film anemometers
- a two-cell infrared gas analyzer for simultaneous measurement of N_2O and SF_6 concentrations
- a "home-made" automatic pneumatic scanner
- an automatic acquisition system
- a barometer
- a thermometer
- a differential pressure meter

The air flow meter is mounted on the intake duct, upstream of the fan when the CVC is overpressurized, downstream of the fan in the other case. It is based on the hot film anemometry principle, and has an accuracy of 2% of the reading + 0.2% of full scale.

Air velocity measurements are realized by means of six high precision, low-velocity hot film anemometers, providing the modulus of air speed. They are mounted on a moveable structure whose position may be changed from the outside. This structure is also used to carry the tubes for air sampling to the gas analyzer. Their accuracy is 1 % of full scale.

The two-cell infrared gas analyzer can provide simultaneous reading of the concentration of two tracer gases (SF_6 and N_2O) from 0 to 200 ppm with an accuracy of 2 % full scale. The analyzer is equipped with special filters to avoid the influence of water vapour variations on the measured value. The outfit of the ventilation laboratory includes pure oxygen protoxide, sulphur hexafluoride, pure nitrogen to test the zero of the instrument and two mixtures of N_2O-nitrogen and SF_6-nitrogen to be used as references.

Three supplementary manual instruments are also part of the CVC experimental apparatus: a barometer and a thermometer, needed to correct for air pressure and temperature variations in measuring the air volume flow rate, and a differential pressure meter, with an accuracy of 1 Pa.

2.3 Control and acquisition

Automatic scanning of channels through which air is sampled and introduced into the infrared analyzer has been built in the lab using a PC both for the control of the pneumatic scanner and for the data acquisition and elaboration. The schematic of the Data Acquisition and Control System is provided in fig. 3.

The control section and the acquisition section are connected to the PC filling the eight-line capacity of the BUS. The control section consists in an I/O interface, a high voltage decoupling device, a power section, and by six electrovalves. The acquisition section consists in an I/O interface, and A/D converters of the signal from the transducers (flow rate, velocities and concentrations).

The schematic of the pneumatic scanner is shown in Fig. 4.

An OUT instruction from the PC opens valve 1 and 2, while the two-way valve 7 lets the air stream sampled through channel 1 to reach the analyser, and the three-way valve 8 "prepares" channel 2 filling it with air sucked by pump 2. As soon as the measurement in channel 1 is completed, valve 1 is closed and valve 3 is opened, and the two three-way valves 7 and 8 reverse their operation. In this way the air stream through channel 2 is admitted to the analyser, while channel 3 is prepared. And so on.

3. Potential uses of the CVC

The CVC will be used to test experimental techniques for the measurement of ventilation rates in buildings, and for the determination of ventilation efficiency and pollutant removal efficiency under different ventilation strategies. It will also be employed to study contaminant diffusion between rooms and within a single room, and to validate 2-D and 3-D fluid dynamics codes. Another possibility will be the test of Demand Controlled Ventilation Systems, i e, those ventilation systems in which the air flow rate is adjusted according to the level of a suitable contaminant chosen as an indicator of indoor air quality (e g, carbon dioxide, water vapour, etc.).

3.1 Measurement of ventilation frequency with novel experimental techniques

The equation of continuity, written for a tracer gas within a confined space of volume V, under perfect mixing hypothesis (i e, uniform concentration), yields:

$$V \cdot dC(t)/dt = \dot{V}(t) \cdot [C_b(t) - C(t)] + \dot{V}_g(t) \qquad (1)$$

Solution of Eq. 1 when both volume air flow V(t) and V_g are a function of time may be difficult. Therefore, usual experimental techniques adopt procedures aiming at the simplification of Eq. 1. First of all, they all adopt tracer gases whowe concentration in the outdoor air may be assumed equal to zero (C_b = 0). Moreover, special modes of injection of the tracer gas are adopted to further simplify the solution of Eq. 1. According to such modes, these methods belong to one of the three following categories:

1. Decay method ($\dot{V}_g = 0$)
2. Constant concentration method (dC/dt = 0)
3. Constant flow method ($\dot{V}_g$ = constant)

The first method, although requiring a very simple apparatus, does not allow accurate evaluations of air exchange rates when this varies with time. The second method is the most accurate, but requires a very expensive apparatus in order to adjust the tracer gas flow rate in such a way that the concentration keeps constant. Finally, the third method has the same limitations of the first one, while requiring large amounts of tracer gas.

For the aforementioned reasons, there may be some interest in developing simple experimental techniques which yet allow the accurate determination of variable frequency of air change. The idea is to adopt sophisticated numerical techniques to solve Eq. 1, while reducing the complexity of the experimental procedure. A numerical technique which can be conveniently adopted to solve Eq. 1 is the so-called "black-box identification" technique. In fact, Eq. 1 may be rewritten in a time discrete form (δ = time step) by means of an ARMA model as follows:

$$C(t) = \sum_{1}^{m} a_i \cdot C(t - i \cdot \delta) + \sum_{0}^{m} b_i \cdot \dot{V}_g(t - i \cdot \delta) \quad (2)$$

Eq. 2 represents the diffusion of a contaminant within a confined space. The model order m is representative of the complexity of the real system (i e, the tracer gas in the air). A model order equal to 1 corresponds to a lumped parameters system, i e, in our case, to a uniform concentration situation. Whether the real system exhibits a strong zonization, the model order will correspond to the number of interconnected zones.

For a first order model (m = 1) and no tracer gas injection (V_g = 0), Eq. 2 reduces to:

$$C(t) = a_1 \cdot C(t - \delta) \quad (3)$$

where coefficient a_1 is named the "direct link".

In this case, Eq. 1 allows a simple analytical solution, i e:

$$C(t) = C(0) \cdot \exp(-t/\tau) \quad (4)$$

or

$$C(t) = C(0) \cdot \exp(-t \cdot n) \quad (4')$$

Equalizing Eqs. 3 and 4 at time t = δ one gets:

$$a_1 = \exp(-\delta/\tau)$$

and

$$\tau = -\delta/\ln(a_1) \quad (5)$$

or

$$n = 1/\tau = -\ln(a_1)/\delta \quad (6)$$

It can be shown that Eq. 6 stands also for more complex situations ($m > 1$, and $V_g \neq 0$), provided that the main time constant of the system is much larger than the other ones. Therefore, under the hypothesis of quasi-perfect mixing (i e, quasi-uniform concentration), knowledge of direct link a_1 may lead to determine the number of air changes.

Coefficients $a_1 \ldots a_m$ and $b_0 \ldots b_m$ of Eq. 2 may be determined using a black-box identification approach, e g, by means of SIMIDE, an extended least squares method which has already been used for the identification and simulation of dynamic thermal systems with very satisfactory results (Calì et al., 1983).

The procedure which has just been described will enable to determine in a discrete form the time series of the ventilation frequency, provided the time series of tracer gas flow rate is known and concentrations are measured.

3.2 Air quality measurements

Measurements described in the previous paragraph refer to a situation where quasi-perfect mixing of a tracer gas occurs.

However, there are many situations when the main interest is focused on the pollutant removal efficiency of a ventilation system. In these cases, the hypothesis of uniform mixing are often no longer valid, and, on the opposite, the pollutant concentration distribution within the space and from room-to-room has to be investigated.

Therefore, the CVC has been equipped with the six-channel pneumatic scanner, which drives the sampled air from six different levels to the gas analyzer. The vertical rod on which the air sampling ducts are mounted may be moved around the room using appropriate displacement systems. An automatically driven mechanism is provided for and will be soon completed for the purpose.

In order to complete the information derived from pollutant concentrations, the CVC has been equipped with six hot film anemometers, located on the same vertical rod used for the air sampling ducts.

4. Preliminary results

A calibration campaign of the CVC has started a few weeks ago. The intent is to verify the reliability of the experimental apparatus under different conditions. At first, the conventional decay method has been tested with overpressurized CVC.

Results are summarized in Fig. 5 and 6. Fig. 5 shows a comparison between the theoretical (perfect mixing) decay of concentration calculated from the values of volume flow rate measured by the flow meter placed on the inlet duct (solid lines) and the actual concentration data (symbols). Fig. 6 shows the time outline of the percent error, i e, the difference between the theoretical and measured values referred to the theoretical value.

From both figures it appears clear that the quality of results is rather good for $n = 1.0$ and $n = 2.0\ h^{-1}$, while the initial estimate of airchanges is rather poor for $n = 0.5\ h^{-1}$. In all cases, the error reduces with time. It ranges from -33 % (at t = 15') to -2 % (at t = 105') for $n = 0.5\ h^{-1}$, from -8% (at t = 15') to almost zero (at t = 120'), from -3 % (at t = 15') to + 3% (at t = 60').

A second campaign was performed in order to test the CVC as regards the measurement of ventilation efficiency, defined as:

$$\epsilon_j = C_e/C_j \qquad (7)$$

Three balanced ventilation strategies, illustrated in Fig. 7, have been tested.

In all cases the nominal ventilation frequency was 3 ach, the starting concentration of the tracer gas was uniform and equal to 200 ppm, and no tracer gas was injected during the measurement ($\dot{V}_g = 0$). Figures 8 to 10 show the time trend of ventilation efficiency at different heights above the floor in the middle of the room for the three cases.

Strategy A (Fig. 8) shows a good ventilation efficiency ($\epsilon > 1$) from 0 to 80 cm above the floor, but at higher levels ϵ is always less than 1. There is also a clear indication of a "diverging" air quality situation.

In strategy B (Fig. 9) the situation is generally better, with $\epsilon >$ 1 at all levels, but with a marked improvement below 1.2 m. After half an hour (1.5 times the nominal time constant) perfect mixing conditions are achieved again.

Strategy C (Fig. 10) shows an interesting and unexpected finding: concentration remains uniform (perfect mixing) all over the CVC, and equals the value at extraction.

Figure 11 allows a good summing up of the three strategies, providing the log concentration decay together with the theoretical curve (straight line). While case C is very close to the theoretical curve, case A shows a marked upward concavity, an evidence of poor performance of the system, and case B shows a marked downward concavity, an evidence of good performance of the system.

A clear indication of the performance of the three systems is the volume of tracer gas extracted by the system during time t:

$$V_g = \int_0^t \dot{V}_g \cdot C_e \, dt$$

The higher the value of V_g, the better is the performance of the system. The measurements confirm the above conclusions, yielding:

strategy	V_g (m^3)
A	0.001917
B	0.002700
C	0.002375

5. Acknowledgements

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6. References

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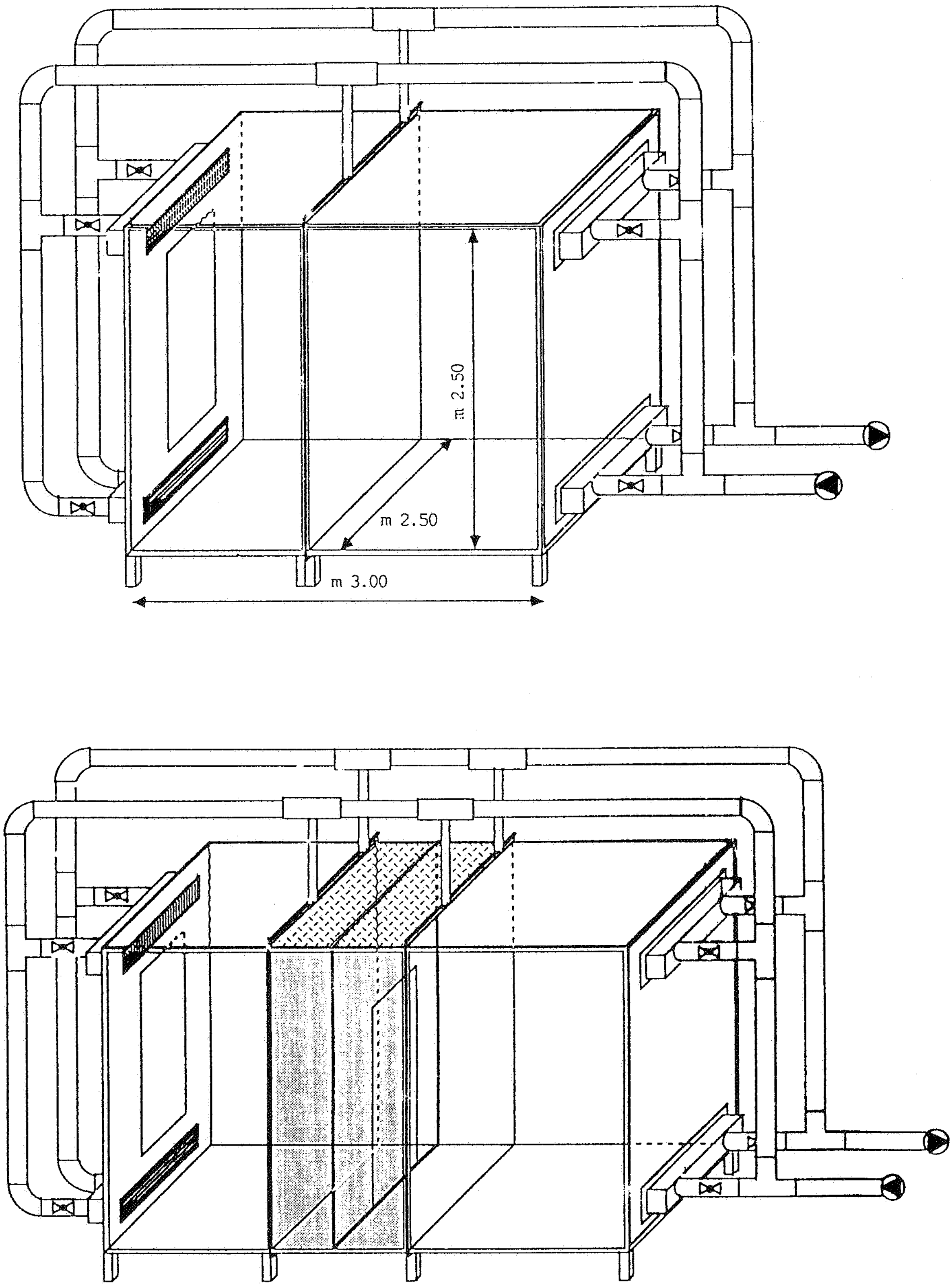


Fig. 1 - The Controlled Ventilation Chamber (CVC)

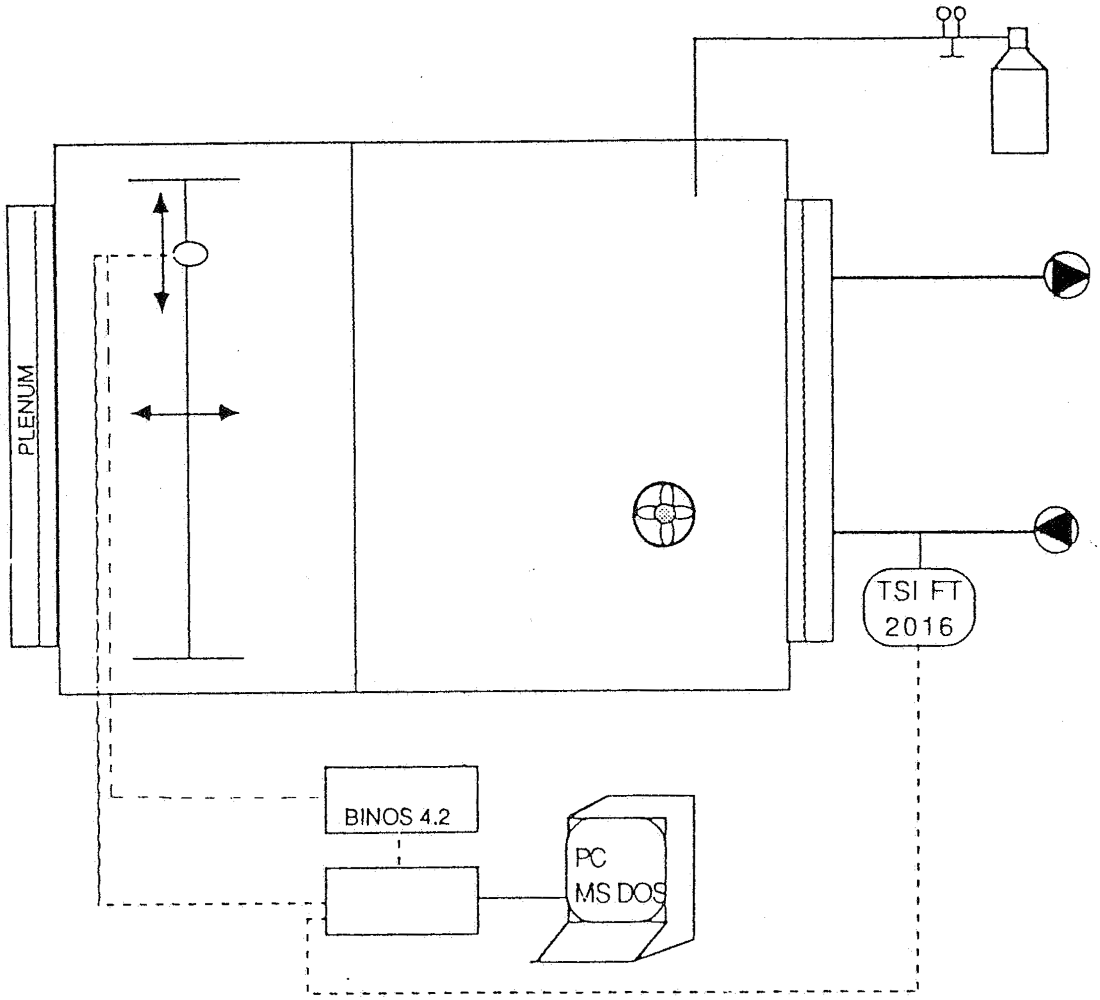


Fig. 2 - Layout of the instrumentation of the CVC

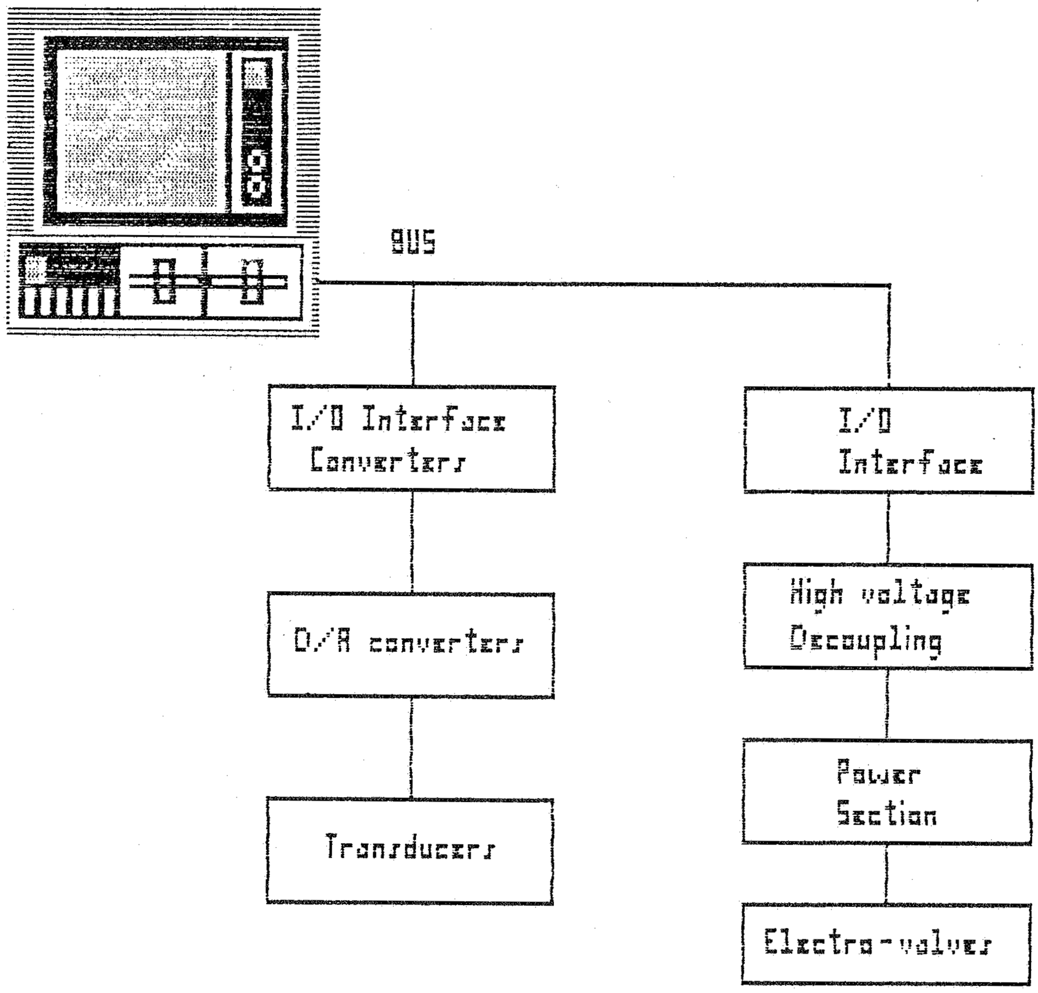


Fig. 3 - The Data Acquisition and Scanner Control System

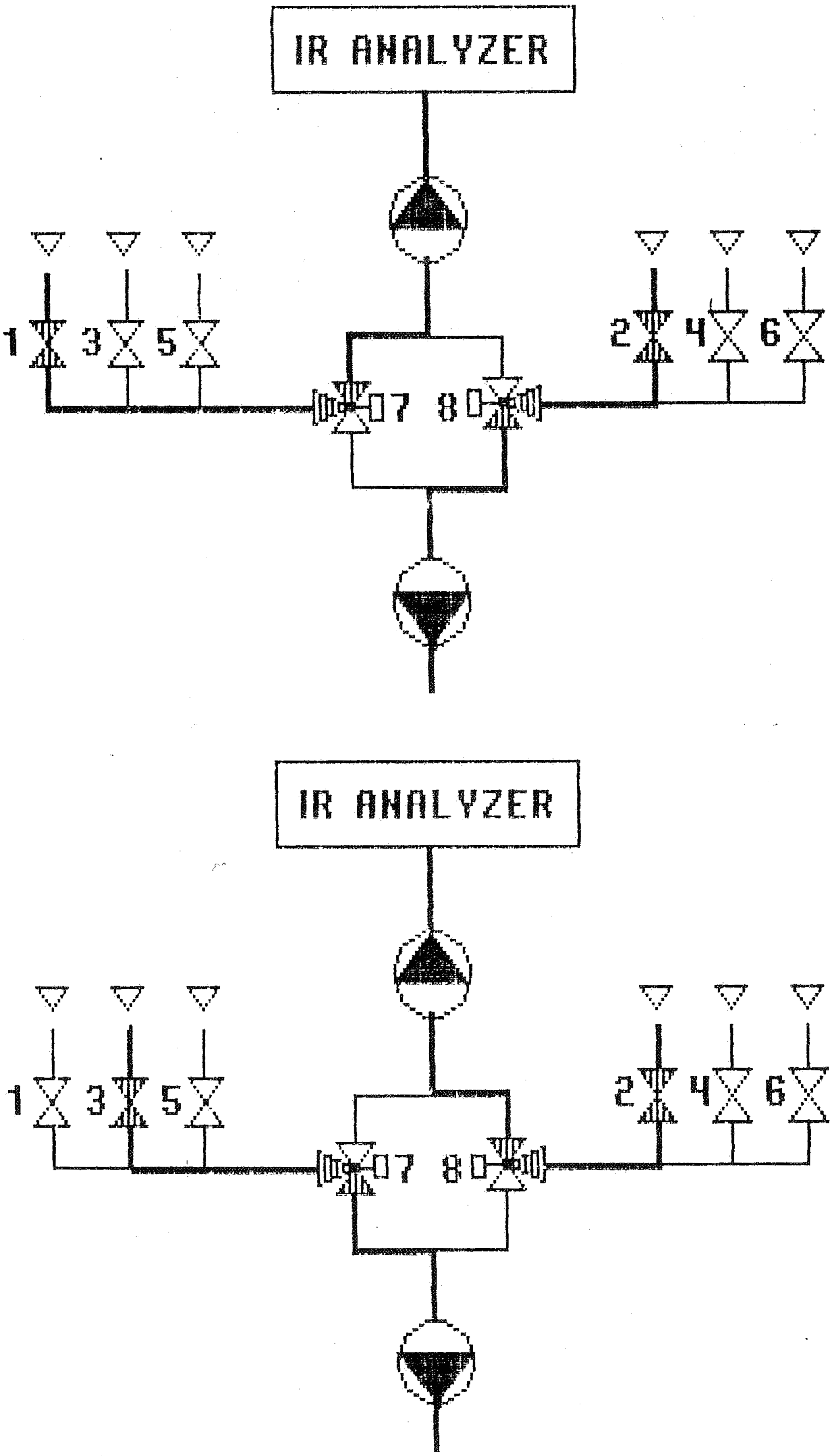


Fig. 4 - The Automatic Pneumatic Scanner

Fig. 5 Measured and estimated N2O concentration decay

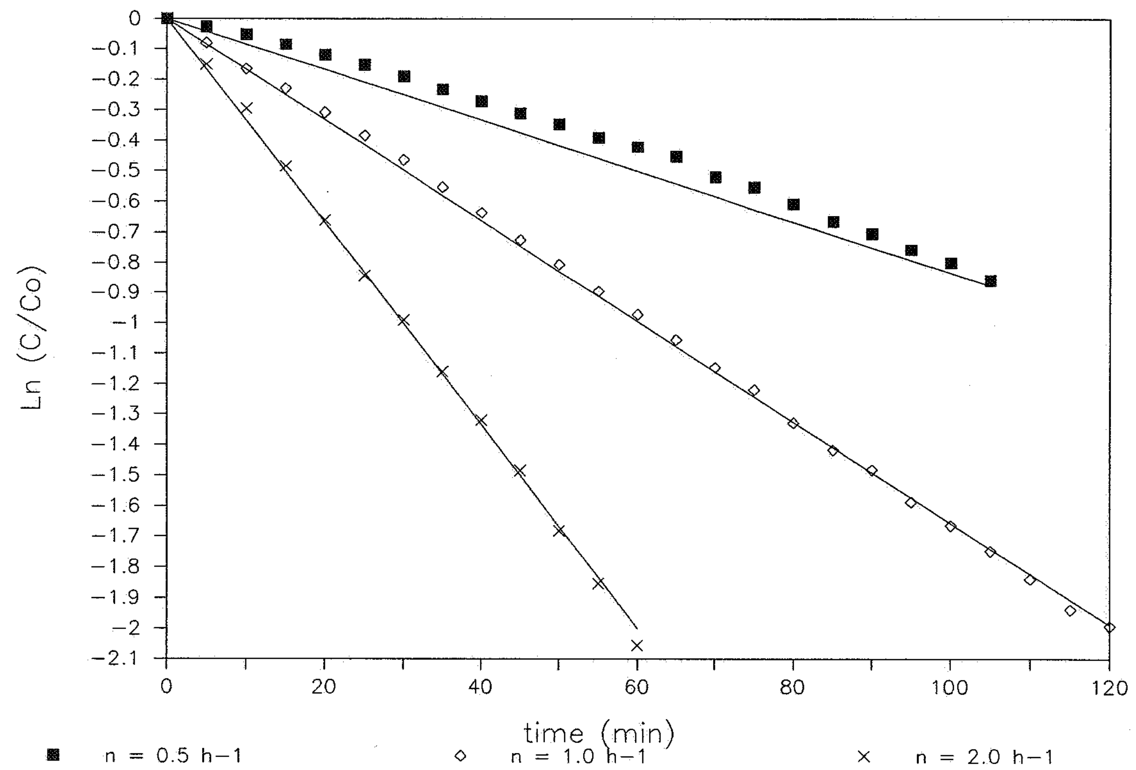
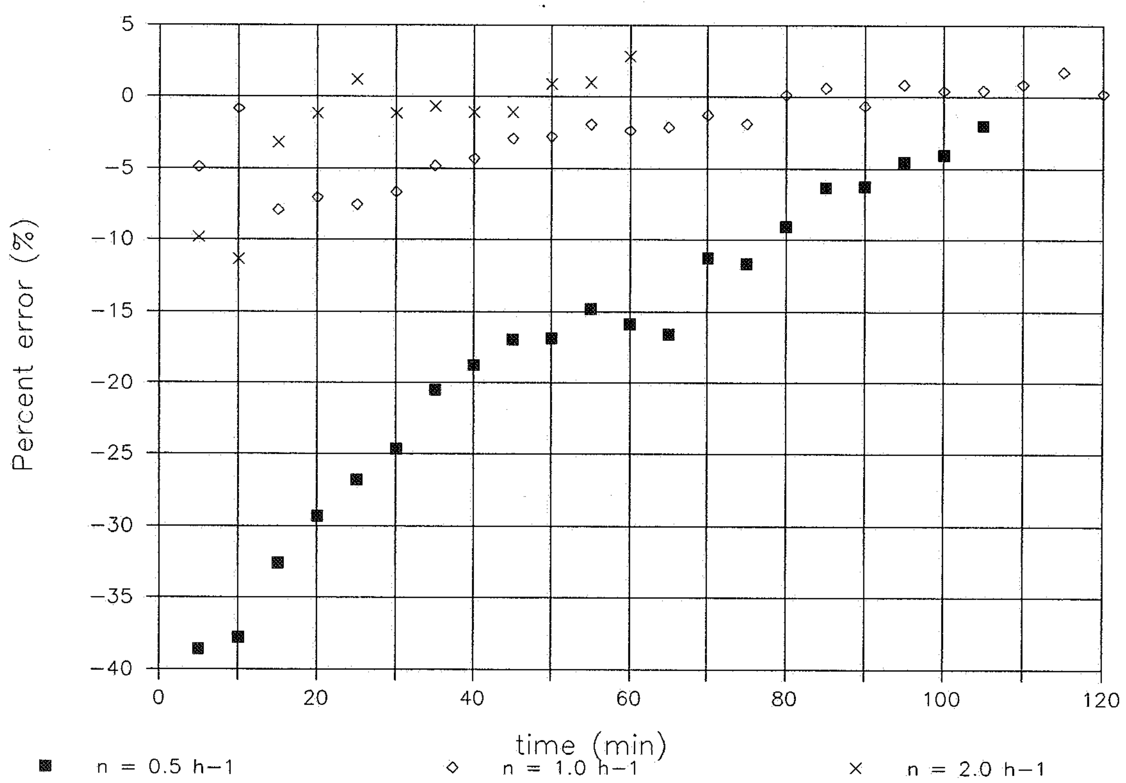


Fig. 6 Percent error vs. time



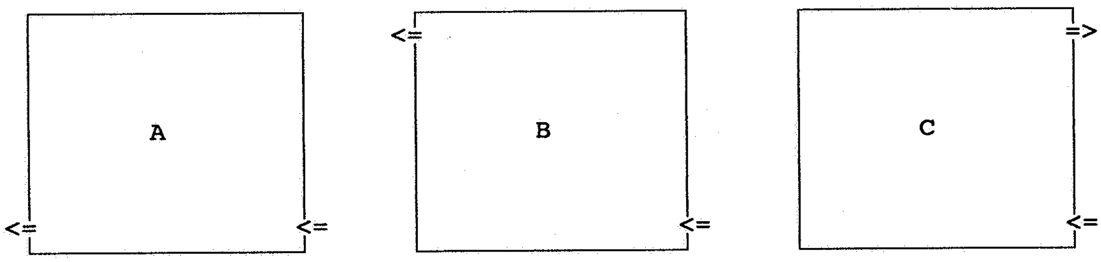


Fig. 7 - Ventilation strategies.

Fig. 8

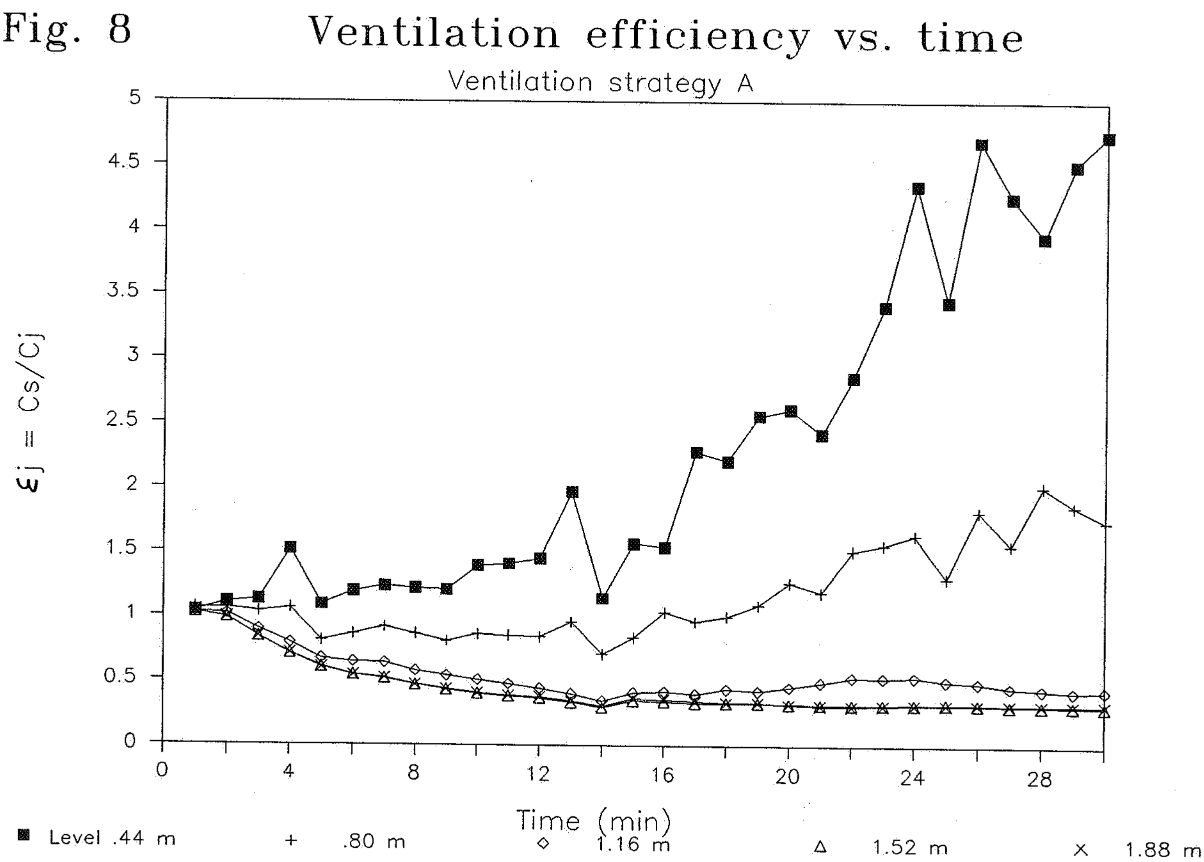


Fig. 9 Ventilation efficiency vs. time

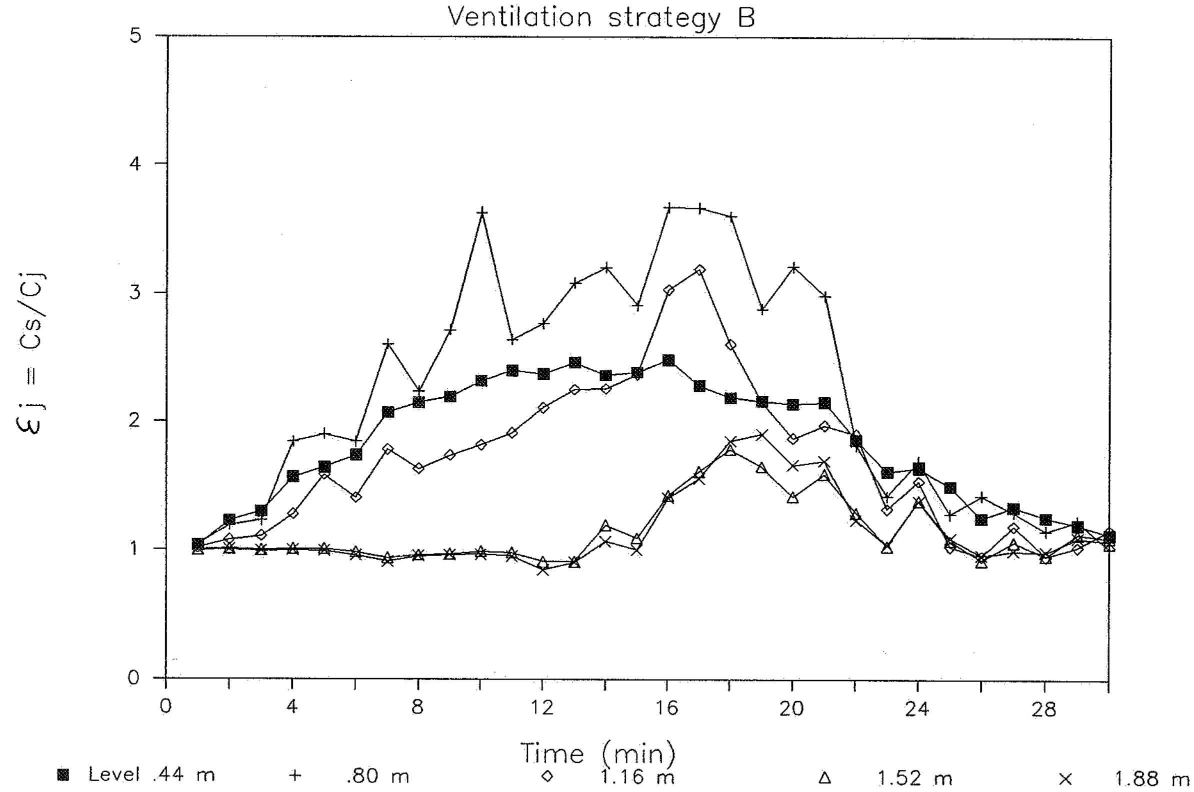


Fig. 10 Ventilation efficiency vs. time

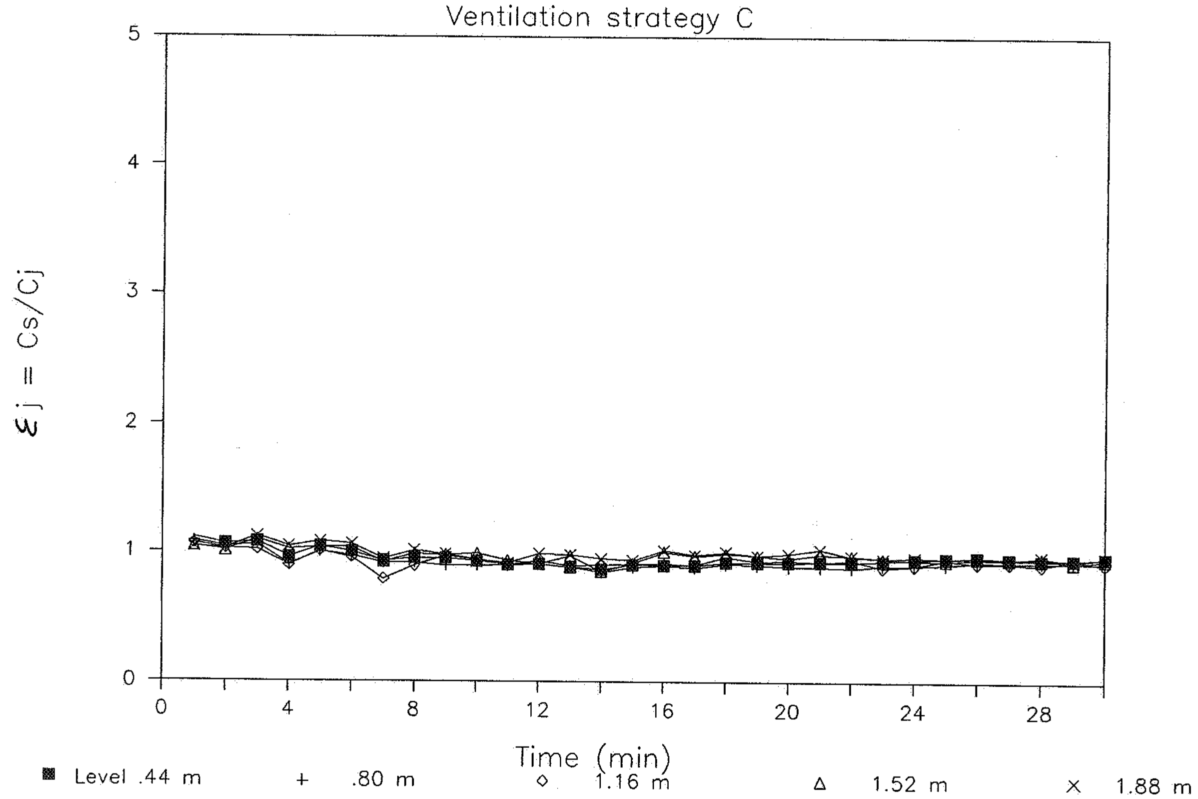


Fig. 11 Concentration in exhaust air terminal