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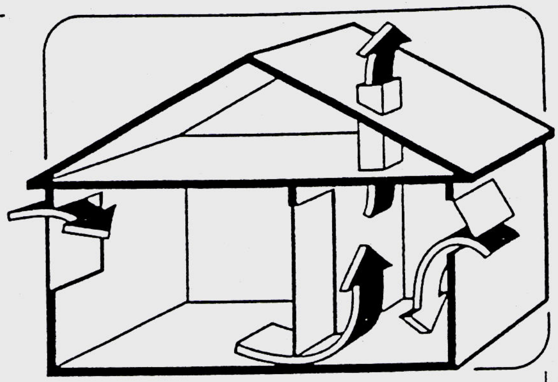

VENTILATION EFFICIENCY MEASUREMENTS IN SULZER TEST CHAMBER

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FINAL REPORT

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SUMMARY

Measurements with tracer gases were performed, together with more classical temperature and air velocity measurements, on various ventilation systems installed in the test chamber of SULZER INFRA, in Winterthur. The test chamber was arranged to simulate an office room, with heat generated from computers and occupants. Moreover, the contaminants from one occupant was simulated with a tracer gas. This document addresses the measurement of the age of the air and of the contaminant removal effectiveness at various locations.

Both displacement and mixing ventilation systems were tested, the latter with two different inlets. Two types of cooling ceilings, a closed, continuous one and a structured one, were installed.

As expected, both mixing system, measured with the continuous cooling ceiling "on", reach nearly complete mixing, hence an air change efficiency of nearly 50 % and a contaminant removal effectiveness close to 1.

Displacement ventilation systems showed a larger air change efficiency in most cases. However, the cooling ceiling counteracts the displacement and important mixing is observed when it is on, mainly if the air flow rate is lower than 5/h. A test without cooling showed a strong displacement effect, the local mean age at all locations corresponding to an occupant being lower than the room mean age. Except in this particular test, the contaminant removal effectiveness is generally about 1. It should be noted that, for these latter measurements, the contaminant source was not far from the inlet grilles, which represents the worst possible case.

RÉSUMÉ

Différents systèmes de ventilation installés dans la chambre d'essais de Sulzer Infra, à Winterthur, ont été mesurés, d'une part en examinant les champs de vitesse et de température, et d'autre part au moyens de gaz traceurs. La chambre a été aménagée de manière à simuler un bureau, comportent des occupants et des appareils générant de la chaleur. De plus, les polluants provenant d'un occupant ont été simulés au moyen d'un gaz traceur. Ce document présente les résultats des mesures d'age de l'air et d'efficacité d'élimination des polluants à plusieurs endroits dans la chambre.

Aussi bien des systèmes de ventilation par déplacement que des systèmes à mélange ont été examinés, ces derniers avec deux différents types de bouches d'entrée. Deux types de plafonds refroidissant ont été installés, l'un continu et l'autre structuré.

Comme on pouvait s'y attendre, les systèmes à mélange, mesurés avec le plafond refroidissant continu enclenché, atteignent pratiquement le mélange total, donc un rendement de renouvellement d'air de 50% et une efficacité d'élimination des polluants de 1.

Les systèmes à déplacement atteignent, dans la plupart des cas, un rendement de renouvellement d'air supérieur. Cependant, le plafond refroidissant contrarie le mouvement de piston, et un mélange relativement important est observé lorsqu'il est enclenché, en particulier avec des taux de renouvellement d'air inférieurs à 5/h. Les mesures sans plafond refroidissant montrent un effet de piston très net, et l'age de l'air près de tous les occupants est inférieur à l'âge moyen dans la pièce. A part dans ce dernier cas, l'efficacité d'élimination des contaminants reste généralement proche de 1. Il faut noter toutefois que, pour ces dernières mesures, la source de polluant n'était pas très éloignée des bouches d'entrée, ce qui représente un cas très défavorable.

INTRODUCTION

Within the frame of the Swiss national Program "Energy and Air Flow Patterns Within Buildings" is was intended to evaluate several new ventilation systems and tests in a climatic chamber were especially planned for that purpose. Therefore, some such systems were installed in the SULZER test chamber, and various measurements were performed.

The LESO-PB was asked to prepare an experimental plan for such measurements and mandated to develop a computer program to interpret age of air measurements, to act as a consultant for such measurements and to prepare this report.

This report is organised in three parts:

1. Planning of the experiments
2. Age of air measurements: techniques and interpretation method
3. Results of the measurements

1. PLANNING OF THE EXPERIMENTS IN THE CLIMATIC CHAMBER

1.1. Introduction

The scope of the global experiment is to evaluate various systems, that is to answer the following questions:

1. how does that ventilation system perform to bring fresh air to the occupants?
2. how does that ventilation system perform to evacuate contaminants from a room?
3. how does that ventilation system perform to evacuate heat from a room?

To answer question 1, the age of air was measured at various locations within the room. To evaluate question 2, a contaminant source is placed within the room, and the contaminant concentration is measured at various locations in the room. For question 3, .temperature and heat flow rates were measured by SULZER, and will be presented in another report.

The purpose of this chapter is to bring some information on the use of the Theory of Experiment Planning to minimise the number of experiments. This point was quickly found essential, since, within the very limited budget, it was obviously not possible to perform extensive expensive experiments.

1.2. Experimental plans

The planning presented below is good to determine the most important parameters within the list of examined parameters, or to fit a linear model on few measurements.
From a minimum number of experiments, the effects (i.e. age of air, temperature, comfort, etc.) can be modelled using a linear approximation:

$$y_j = a_o + \Sigma_i a_{ij} x_{ij} + \Sigma_{i k} b_{ik} x_{ji} x_{jk} \qquad (1)$$

where:

y_j is the effect measured in experiment j
x_{ij} is the value of variable i in experiment j
a_{ij} and b_{ik} are the coefficient of the model to be determined.

The coefficients a_{ij} are directly related to the importance of each effect and the coefficients b_{ik}, if used, determine the importance of the interactions between variables. These coefficients are obtained by solving the system (1) after having performed the experiments.

1.2.1. Variables

Numerous parameters may have some influence on the internal air flow pattern, on the temperature distribution and on the indoor air quality. We can enumerate the following ones, without claiming to be exhaustive:

- Parameters linked to the **room**: dimensions, furniture and occupancy, location and strength of the heat and contaminant sources, distribution and magnitude of infiltration paths, location of the occupants.
- Parameters linked to the **ventilation system**: ventilation type, type and location of inlets and outlets, air flow rate, air temperature.
- Parameters linked to the **heating and cooling systems**: type of these, installed power, temperatures.

A study involving variations of all of these parameters, even well planned, would be very large. To take account of the limited budget, the number of parameters allowed to vary in the present study were restricted. to a small number. In particular, the room was always the same: square 7,25 × 7.25 m floor, and 3 m height. Furniture, sources and simulated occupancy was installed as shown on figure 1.

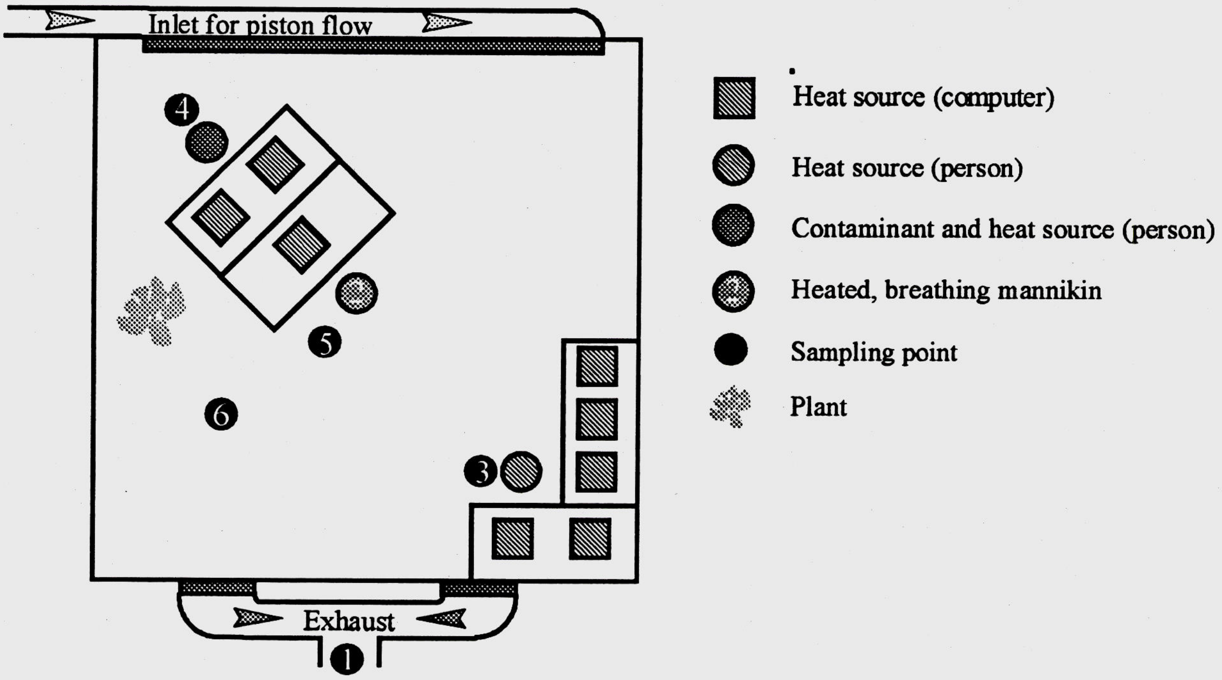


Figure 1: Plan of the test chamber with furniture, occupants and sampling points. Scale is 1:100. Sampling points are at 1.1 m, except at location 5 where air is sampled at 0.2, 0.7, 1.1, 1.3 and 1.8 m.

The parameters which were varied during this study are those shown on Table 1. Two ventilation systems (with variants) were tested, at various heat load and air flow rates. The internal loads were evacuated either totally or partially by the ventilation, the other part being removed by a cooled ceiling, which could be on or off. Remaining planned parameters were:

- internal load, related to floor area, in W/m²,
- convective part in that load, that is part of the load which is transmitted to the air, and
- specific air flow rate, related to floor area.

With cooling ceiling, the internal load could be higher, and the air flow rate could be reduced. Therefore, the limits are not the same with or without cooling.

Table 1: List of parameters which were varied in this study, together with their planned limits.

Parameter		Minimum	Maximum	Unit
Ventilation system		Piston type	Mixing	
Cooling ceiling		off	on	
Internal load	Cooling	10	30	W/m^2
Convective part in load	off	20	50	%
Specific air flow rate		10	20	$m^3/(h\ m^2)$
Internal load	Cooling	30	90	W/m^2
Convective part in load	on	20	80	%
Specific air flow rate		5	20	$m^3/(h\ m^2)$

1.2.2. Proposed first experimental plans

Several experimental plans were proposed before doing the measurements, as a basis for the choice of the definitive experiments. These proposals are based on the theory of experimental planning, and provide a minimum number of experiments allowing one to assess the parameters of equation 1 with a maximum accuracy. Since the number of varying factors is finally small, half factorial, two-level designs are proposed. To improve the accuracy on a_0, experiments could be added with all variables at mid-range.

The cases with and without cooling ceiling and the case with complete mixing are treated separately. All the experimental plans are based on the same frame, which is a 4 experiments partial factorial plan for three variables. Normalising the extreme values of each variable to -1 and +1, this plan is:

Variable		
1	2	3
-1	-1	1
1	-1	-1
-1	1	-1
1	1	1

When this plan is applied to the three cases mentioned above, we get the experimental conditions for the planned experiments shown on Table 2. Note that for the mixing ventilation systems, the convective part of the hat load was planned to be always 50%.

1.3. Experiments performed

The experiment finally performed were not exactly those planned, first because the limits of variation for some variables were changed after the first experiments. Moreover, the convective part of the load was not changed, but two types of cooling ceilings were tested. Most of the tests were performed with the ceiling cooling "on".

Therefore, the optimal experimental planning should be changed as shown in Table 3.

Table 2: First planned experimental conditions. Air change rate [/h] is one third of the specific air flow rate.

Ventilation system	Cooling	Specific air flow rate. m³/h, m²	Internal load W/m²	Convective part %
Piston	off	10	10	50
Piston	off	20	10	20
Piston	off	10	30	20
Piston	off	20	30	50
Piston	on	5	30	80
Piston	on	20	30	20
Piston	on	5	90	20
Piston	on	20	90	80
Mixing	off	5	30	50
Mixing	off	20	30	50
Mixing	off	5	90	50
Mixing	off	20	90	50

Table 3: Modified experimental planning .

Ventilation system	Ceiling type	Cooling	Specific air flow rate. m³/h, m²	Internal load W/m²
Piston		off	10	10
Piston		off	20	10
Piston		off	20	30
Piston	Closed	on	5	30
Piston	Structured	on	20	30
Piston	Structured	on	5	90
Piston	Closed	on	20	90
Mixing	Closed		5	30
Mixing	Closed		20	30
Mixing	Closed		5	90
Mixing	Closed		20	90

However, this plan was even not exactly followed. the reasons why being the following:

- In order to adapt the program to the limited budget, the number of experiments was diminished. Therefore, the internal heat load was restricted to two values, namely 60 W/m² for mixing ventilation or when cooling, and 20 W/m² with piston ventilation without cooling. That means that no information on the effect of internal heat load can be assessed.

- Specific air flow rate was limited between 5 and 15 $m^3/h.m^2$ for piston ventilation, and fixed to 10 $m^3/h.m^2$ for mixing ventilation.
- Measured information was lost for one experiment (piston ventilation at higher air flow rate without cooling ceiling) because of electric power failure.

The characteristics of the performed experiments are summarised on Table 4.

Table 4: Conditions in which the experiments were performed. Air change rate [/h] is one third of the specific air flow rate.

Experiment number	Ventilation system	Cooling ceiling		Specific air flow rate. $m^3/(h, m^2)$	Internal load W/m^2
I	Mixing (Vortex)	closed	on	10	60
II	Mixing (Slots)	closed	on	10	60
III	Piston	N/A	off	10	20
VI	Piston	closed	on	5	60
VIII	Piston	closed	on	15	60
IX	Piston	structured	on	5	60
X	Piston	structured	on	10	60
XI	Piston	structured	on	15	60

1.4. Location of the sampling points

An essential sampling point is the exhaust duct. The concentration of tracer gas at this location is required for the calculation of contaminant removal effectiveness, of specific air flow rate (air change rate) and of room mean age of air. The location of the other points were chosen according the following considerations:

- The total number of points should be limited to 6, which is the number of entries in the Brüel and Kjaer scanner.
- This number is not sufficient to perform a map of the concentration. Therefore, a mapping plan is not appropriate in this case.
- The highest attention should be paid to the occupants.

As shown on Figure 1, the sampling points are:

1 exhaust,
2 within the lungs of the breathing, heated mannequin;
3 close to the heated cylinder simulating an occupant at a working place in the corner, 1.1 m. high,
4 close to the heated cylinder simulating an occupant at a working place at the desk, 1.1 m. high, facing the mannequin;
5 not far from the mannequin, in order to see the difference between the environment of an occupant and the air she breathes, which could come from his plume,
6 at a location, 1.1 m. high, far from any occupant, heat source or wall.

For contaminant removal effectiveness measurements, the contaminant source was placed on occupant 4.

1.5. Measurement strategy

1.5.1. Age of air

The measurement of the age of air requires the monitoring of concentrations versus time. However, this concentration cannot be recorded continuously, because of the analysis time (1 minute). Therefore, the time between two measurements at the same location is equal to the number of scanned locations, in minutes. In order to follow the changes in concentrations required for the age of air measurements, this interval should not be too large. Previous experiments showed that the time interval should not exceed the quart of the nominal time constant. Therefore, the number of measured points in an experiment cannot exceed the values given in Table 4. If this number is lower than 6, the experiments should be repeated, with the same conditions but other sampling points, until all the 6 points are measured.

Table 4: Maximum number of sampled points for the measurement of the age of air.

Air change rate	<2.5	<5	<7.5	h^{-1}
Nominal time constant	>24	>12	>8	minutes
Number of points	6	3	2	
Number of experiments	1	2	3	

1.5.2. Contaminant removal effectiveness

This quantity is defined in steady state, and tells how effectively a contaminant is removed before reaching a location of interest. For such measurements, a contaminant source should be installed and concentrations of the contaminant should be measured, once the steady state is reached, at the exhaust and at any place of interest.

In the present case, N_2O was used as tracer, the source being the occupant 4. The tracer gas simulates any contaminant coming from that occupant, for example body odour or cigarette smoke. This occupant was chosen as a worst case, since he is away from the air exhaust grilles and close to the breathing mannequin.

Contaminant concentration were performed at the 6 locations mentioned above, then at location 5 at 5 different heights, i.e. at 0.2, 0.7, 1.1, 1.3, and 1.8 m., to get an idea of the vertical distribution of the effectiveness.

2. MEASUREMENTS: TECHNIQUES AND INTERPRETATION METHOD

2.1. Age of the air

2.1.1. Definition of the age of air

The quantities defined below are explained in greater detail in the literature *[1, 2, 3]* and are only briefly described here. The particles of fresh air coming from outside or from the ventilation system arrive at a given location ***r*** in a room after a time $\tau(\boldsymbol{r})$ which will vary from one particle to the other. τ is called the residence time of the particle in the room, or its age, as if it were born when entering the room. Since there is a large number of air particles, we may define a probability density $f_r(\tau)$ that the age of particles arriving at a given location is between τ and $\tau+d\tau$ and a probability $F_r(\tau)$ that this age is higher than τ. The following relationships always hold between these two functions:

$$\frac{dF_r}{d\tau} = f_r(\tau) \quad \text{and} \quad \int_0^\infty f_r(t)\, dt = F_r(\tau) \qquad (2)$$

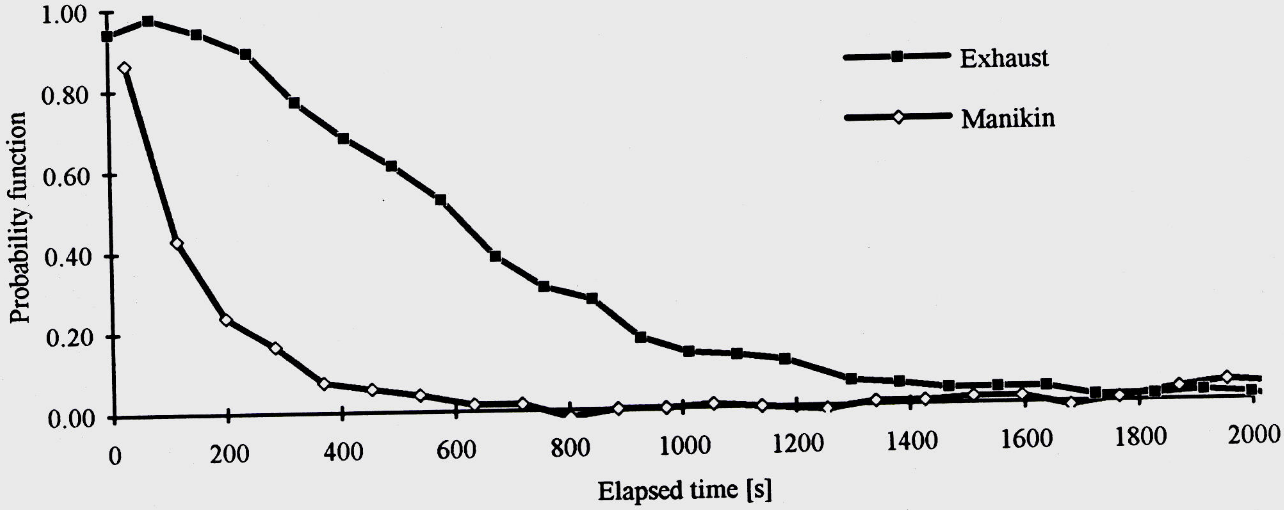


Figure 2: Probability $F_r(\tau)$ that the age of the air is higher than a pre-defined value, measured at two locations during experiment VIII

The **local mean age of air** at a point ***r***, $\bar{\tau}_r$, is defined by the average age of all the air particles arriving at that point:

$$\bar{\tau}_r = \int_0^\infty t\, f_r(t)\, dt \qquad (3)$$

The **room mean age of air,** $\langle\tau\rangle$, is defined by the space average of the local mean ages of the air particles in the room:

$$\langle\tau\rangle = \frac{1}{V}\int_0^\infty \bar{\tau}_r \, dt \qquad (4)$$

where V is the volume of the room.

2.1.2. Measurement method for the age of the air and related quantities

The basic principle is to mark the air to be traced with a gas (the tracer gas), according to a known schedule, and to follow the concentration of that tracer gas at the location of interest. This technique is based on the assumption that the tracer gas behaves the same as the air: no adsorption, same buoyancy. It can be readily understood that if the air is marked at the inlet by a short pulse of tracer gas, and if the tracer molecules follow the air molecules, they will arrive at a given location at the same time as the air molecules. In fact, the pulse technique is not the only one and the probability functions (2) and the local mean ages (3) can be measured by recording the time history of the net tracer concentration, $C_r(t)$, at any point, $\mathbf{r}$, by either of three strategies as follows:

- **step down:** uniform concentration of tracer is achieved at the beginning of the test, when the injection is stopped,
- **step-up:** the tracer is injected at air inlet, at a constant rate from the starting time throughout the test,
- **pulse:** a short pulse of tracer is released in the air inlet at the starting time.

A recent study *[4]* has shown however that, for rooms with a single air inlet and a single air outlet, the step up method should be preferred, since it is the easiest to perform in that case and gives the best accuracy. Therefore, in the following, we will consider only this case.

To interpret the recorded tracer gas concentrations and obtain the age of air, the background (or supply) concentration should first be subtracted from all measurements, and the elapsed time should be calculated by subtracting the starting time from all time values. In the following formulas, the net concentration, C_r, is the difference between the concentration measured at location $\mathbf{r}$ and the concentration in the outdoor air. The local mean age at a given measurement location is obtained by evaluating the following expressions:

Probability function for the local age of air:

$$F(\tau_r) = \frac{C_r(\infty) - C_r(t)}{C_r(\infty)} \qquad (5)$$

Local mean age of air:

$$\bar{\tau}_r = \frac{\mu_0[C_r(\infty) - C_r(t)]}{C_r(\infty)} \qquad (6)$$

The room mean age of air can also be deduced from tracer concentration measurements in the exhaust, $C_e(t)$, assuming a single exhaust and steady state:

$$\langle\tau\rangle = \frac{\mu_1[C_e(\infty) - C_e(t)]}{\mu_0[Ce_r(\infty) - C_e(t)]} \qquad (7)$$

In equations (6) and (7), the various moments, μ_n, of the concentration are defined by:

$$\mu_n = \int_0^{\infty} t^n \, C_r(t) \, dt \tag{8}$$

If there is only one exhaust (and no ex filtration as well), the nominal time constant of the room, τ_n, which is the ratio of the room volume and the volumetric air flow rate, is equal to the mean age of air at the exhaust, $\bar{\tau}_e$, since at this location, the tracer gas is well mixed with the exhaust air:

$$\tau_n = \bar{\tau}_e \tag{9}$$

Therefore, the air change efficiency, η_a, can be assessed directly by measuring the evolution of the concentration at the exhaust:

$$\eta_a = \frac{\bar{\tau}_n}{2\,\langle\tau\rangle} = \frac{\bar{\tau}_e}{2\,\langle\tau\rangle} \tag{10}$$

2.1.3. Interpretation

In practice, the various moments in the above formulae are calculated numerically, on the base of discrete recorded values of the concentration and time. The following section describes a simple way to calculate these moments, using the trapeze method, whose general formulation is:

$$\int_0^{t_N} f(t) \, dt \cong \sum_{j=0}^{N-1} \frac{f_j + f_{j+1}}{2} \Delta t \tag{11}$$

where f_j is for $f(t_j)$ and Δt for $t_{j+1} - t_j$.

Assuming a linear variation of the concentration in each time step, we get, for the first moments defined in equation (8):

$$\mu_0 = \left(\frac{C_0 + C_N}{2} + \sum_{j=1}^{N-1} C_j \right) \Delta t + \varepsilon_0(N, \tau_d) \tag{12}$$

$$\mu_1 = \left(\frac{1}{6} C_0 + \frac{3N-1}{6} C_N + \sum_{j=1}^{N-1} C_j j \right) \Delta t^2 + \varepsilon_1(N, \tau_d) \tag{13}$$

The number of measurements, N, could be large enough to ensure that the sum of the terms for $j > N$ are negligible, or, in other words, that C_N is very close to the steady state value. In this case, the remaining parts, $\varepsilon_n(N, \tau_d)$, are negligible. In practice, however, the measurement can be stopped before reaching the steady state. In this case, the tail in the integral of the moments is not measured and it should be estimated.

As shown in Figure 3, this tail is, in most cases, exponential. Therefore, for time larger than $t_N = N\Delta t$, it can be assumed that:

$$C_\infty - C(t>t_N) = [C_\infty - C_N] \exp\left(\frac{t_N - t}{\tau_d}\right) \tag{14}$$

where τ_d is a time constant determined by a fit on the last measurements, in the exponential part. The time required for reaching an exponential decay depends not only on the nominal time constant of the room, but also on the ventilation system. In case of complete mixing and at steady state, the decay will be exponential from the beginning of the test. In case of perfect displacement ventilation, the decay will be very sharp after a time equal to the age of air and the concentration might be negligible before presenting an exponential decay.

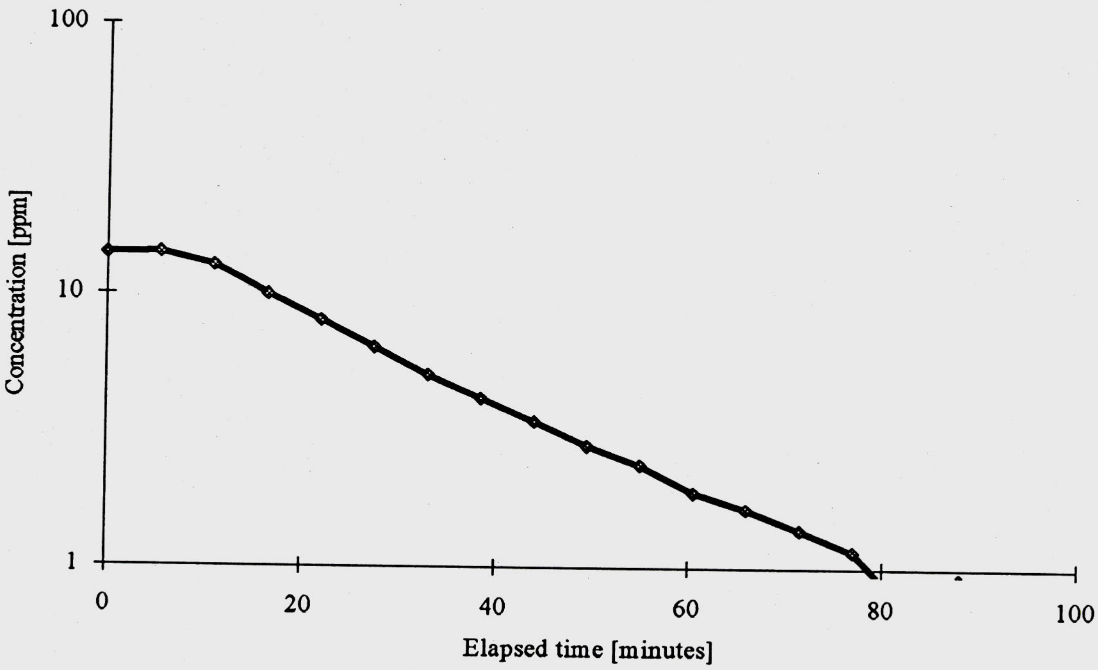


Figure 3: Logarithm of the net concentration $C_\infty - C(t)$ versus time in a measurement. The decay is close to an exponential after 20 minutes, that is a little less than the nominal time constant of the room.

When equation 14 is valid, the remaining part, $\varepsilon_n(N, \tau_d)$, can be calculated analytically and the following expressions are obtained, which can be used in equations 12 and 13:

$$\varepsilon_0 = [C_\infty - C_N]\,\tau_d$$
$$\varepsilon_1 = [C_\infty - C_N]\,\tau_d\,(t_N + \tau_d) \tag{15}$$

Note that a better accuracy can be obtained when applying equations (15) also on the measured part of the exponential tail, as it was observed recently *[4]*.

2.1.4. Error analysis

This analysis intends to provide some guidance on how the measurement errors are propagated through the interpretation formula to the results. The general equation used below assumes that the results of measurements, x_i, are randomly distributed around an average value with a normal distribution, the standard deviation being $\sigma(x_i)$. The estimate σ_y, of the errors on the results, $y(x_i)$, when the errors on the measurements are independent of each other is then:

$$\sigma^2(y) = \sum_i \left(\frac{\partial y}{\partial x_i}\right) \sigma^2(x_i) \tag{16}$$

Therefore, using the equations (6) and (7), we obtain:

$$\frac{\sigma^2(\tau_r)}{\tau_r^2} = \frac{\sigma^2(\mu_0)}{\mu_0^2} + \frac{\sigma^2(C)}{C^2} \tag{17}$$

$$\frac{\sigma^2(\langle\tau\rangle)}{\langle\tau\rangle^2} = \frac{\sigma^2(\mu_1)}{\mu_1^2} + \frac{\sigma^2(\mu_0)}{\mu_0^2} \tag{18}$$

It should be mentioned here that the error of the concentration, $\sigma(C)$, should include the error on the reference concentration too. It could hence be estimated at $\sqrt{2}$ times the error of single concentration measurement.

Assuming an error in the concentration, $\sigma(C)$, which is independent of time, and errors in time $\sigma(t)$ and in the final decay rate, $\sigma(\tau_d)$, the errors in the various moments can be calculated, assuming that integration runs from 0 to $t_N = N\Delta t$ and that the remaining parts are calculated for $t > t_N$ using equation (11). Moreover, in equations (19) to (21), it is assumed that the number of measurements is large enough (e.g. more than 10) and only the largest power of N or t_N is kept in the sums.

$$\sigma^2(\mu_0) = (t_N \Delta t + \tau_d^2)\,\sigma^2(C) + C_0^2 + C_N^2\,\sigma^2(t) + C_N^2\,\sigma^2(\tau_d) \tag{19}$$

$$\begin{aligned}\sigma^2(\mu_1) = &\left(\frac{t_N^3\,\Delta t}{3} + \tau_d^2(t_N + \tau_d)^2\right)\sigma^2(C) \\ &+ (\tau_d^2 + t_N^2)\,C_N^2\,\sigma^2(t) + C_N^2(t_N + 2\,\tau_d)^2\,\sigma^2(\tau_d)\end{aligned} \tag{20}$$

$$\begin{aligned}\sigma^2(\mu_2) = &\left(\frac{t_N^5\,\Delta t}{5} + \tau_d^2[\tau_d^2 + (t_N + \tau_d)^2]^2\right)\sigma^2(C) \\ &+ [4(t_N + \tau_d)^2\,\tau_d^2\,C_N^2 + t_N^4\,C_N^2]\,\sigma^2(t) + C_N^2[2\,(\tau_d + t_N)^2 + 2\tau_d^2]\,\sigma^2(\tau_d)\end{aligned} \tag{21}$$

Calculations of orders of magnitudes of these errors with usual values show that the larger is the order of the moment, the larger the error is. Therefore, error on the room mean age is larger that the error on the local age and the pulse technique induces larger errors than the two other techniques.

Errors in the concentrations have the largest influence. Errors in starting time may be important only in the step-down and step-up methods. Care should also be taken in determining the tail parts, ε_i, according equations (13). Errors in the time constant τ_d may have a large influence and this parameter, if used, should be determined with the best possible accuracy. A recommended technique is a least square fit on the logarithms of the last M concentrations, providing that $M\Delta t \cong \tau_d$ and that this part of the decay is exponential *[3]*. In this study, we have calculated, for each experiment, the optimal value of N to obtain the best accuracy on the age.

A computer program for interpretation of the measurements is written on these basis and is given in annex A.

2.2. Contaminant removal effectiveness.

Contaminant sources are located in the room, and spread their contaminant. For each contaminant, the concentration is measured at location ***r*** and at the exhaust. The contaminant removal effectiveness at location ***r*** is calculated by:

$$\varepsilon_r = \frac{C_e}{C_r} \tag{22}$$

where C_e and C_r are respectively the net concentrations at the exhaust and at the location of interest, resulting from a contaminant source located in the room, and after deduction of the concentration in outdoor air (if any).

This effectiveness is equal to 1 in case of complete mixing, since all concentrations are the same in this case. It is zero when the contaminant appears at location ***r*** but not in the exhaust: the contaminant is not extracted. It is higher than one when the contaminant is efficiently extracted, and may even be infinite, if there is no contaminant at location ***r***.

3. RESULTS

3.1. Age of air measurements

3.1.1. Experimental conditions

According to paragraph 2.1.2 above, the step-up technique was used in all these experiments. The tracer gas (Sulphur hexafluoride) was injected in the air inlet duct, at more than 5 m upwind the inlet grilles. In the first experiment, the injection location was a little closer, and imperfect mixing of the tracer gas in the air was observed, as shown on Figure 4.

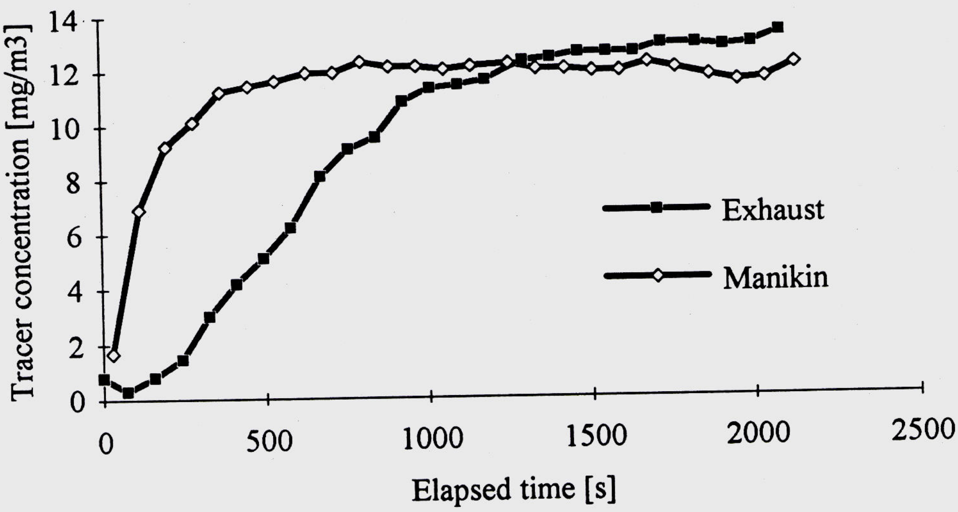


Figure 4: Tracer gas concentration at two different locations in the first experiment. The final concentration should be the same. The observed difference is an indication of unperfected mixing of the tracer in the pulsed air.

Samples of air were taken at fixed time intervals by the sampler and analysed with the Brüel and Kjaer 1302 photo acoustic analyser. The setting of that instrument are shown on Table 5.

Table 5: Settings of the Brüel and Kjaer 1302 photo acoustic analyser

Compensate for Water Vapour Interference	NO
Compensate for Cross Interference	NO
Sample Continuously	YES
Pre-set Monitoring Period	NO
Measure	
Gas A: Carbon dioxide	NO
Gas B: Di-nitrogen oxide	NO
Gas C: Sulphur Hexafluoride	YES
Water Vapour	NO
Sampling Tube Length	16 m
Air Pressure	101.33 kPa
Normalisation Temperature	22 °C

The data were automatically recorded in the B&K format on a MS-DOS floppy disk, which was sent to the LESO. There, these data were first translated by the code TRANSBK to another format, in such a way that they could be used directly as an input file for the code NEWAGE, which calculates the ages of air and their related confidence intervals at the various locations.

3.1.2. General results

The complete results are given in Annex B and summarised in Table 6. The average confidence interval at 95% probability for the age of air is about 1 minute.

Table 6: Summary of the results of age of air measurements.

Test No	Ventilation Type	Cooling ceiling	Heat load W/m²	Air flow rate m³/h	Local mean age of air [min] at location 1	2	3	4	5	6	Room mean age [min]
I	Vortex	Closed	60	526	18	20	20	20	21	21	16
II	Slot	Closed	60	526	22	21	22	24	24	26	20
III	Piston	Off	20	520	22	6	11	14	9	10	16
VI	Piston	Closed	60	268	34	25	33	34	34	35	23
VIII	Piston	Closed	60	788	17	6	16	16	18	19	12
IX	Piston	Structured	60	268	31	32	32	32	33	34	25
X	Piston	Structured	60	526	23	19	23	19	23	22	20
XI	Piston	Structured	60	788	18	8	15	15	15	14	14

3.1.3. Nominal time constant

A first remark is that the nominal time constant can be estimated by two ways: from the measurement of the air flow rate, Q, in the ventilation duct:

$$\tau_n = \frac{V}{Q} \qquad (22)$$

where V is the room volume (157.7 m³ in the present case), or directly from the age of air in the exhaust duct. These two values does not fit in each case, as shown in Table 7.

Table 7: Comparison of two estimates of the nominal time constant [minutes].

Test No	Nominal time constant $\tau_n(e)$ from exhaust	$\tau_n(a)$ from air flow	$\Delta\tau/\tau_a$
I	18	18	0%
II	22	18	-19%
III	22	18	-21%
VI	34	35	4%
VIII	17	12	-33%
IX	31	35	13%
X	23	18	-26%
XI	18	12	-38%

The average relative difference is -12%, the time constant calculated from the tracer gas concentration at the exhaust being larger than this determined from the air flow rate. This systematic difference is larger than the confidence intervals (both being about 5 %) and should therefore be explained.

A possibility is a systematic error in the measurements, but it should be noted that the calibration of the analyser or the mixing of the tracer gas in the inlet air, which are the most likely errors, will have no influence on these results. Another explanation is that a part of the air does not leave the room through the exhaust duct, but through other leakage.

This second explanation is supported by the fact that there is an obvious correlation between the relative difference and the nominal time constant. As shown on Figure 5, for small time constants (large air flow rates, thus high pressure differences) the difference is large and negative, meaning that the exhaust air flow rate is smaller than the inlet flow rate. For large time constants it is the contrary. Moreover, the room is at a higher pressure than the exterior.

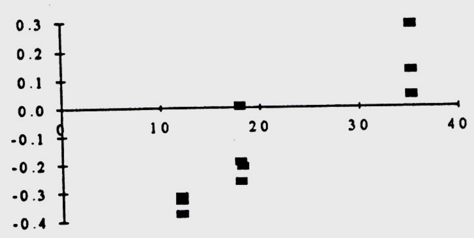


Figure 5: Relative difference between $\tau_n(a)$ and $\tau_n(e)$ versus $\tau_n(a)$

3.1.4. Local mean age

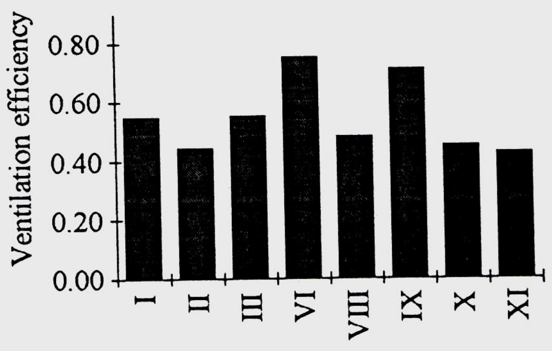
Table 8 and Figures 6 and 7 show the ventilation efficiencies for each experiment and each location from 1 to 6, and the relative local age, defined as the ratio of the local mean age and the room mean age.

Table 8: Local mean ages related to room mean age at the measured locations for the various experiments.

Test No	Ventilation type	Cool	Local mean age / Room mean age at location 1	2	3	4	5	6	Room mean age [min]	Air change efficiency at exhaust	Air change efficiency from flow
I	Vortex	on	1.09	1.19	1.20	1.21	1.26	1.29	16	0.55	0.55
II	Slot	on	1.08	1.06	1.08	1.20	1.21	1.27	20	0.54	0.45
III	Piston	off	1.37	0.39	0.67	0.84	0.57	0.61	16	0.68	0.55
VI	Piston	on	1.44	1.05	1.40	1.44	1.43	1.49	23	0.72	0.75
VIII	Piston	on	1.34	0.51	1.25	1.30	1.42	1.49	12	0.67	0.48
IX	Piston	on	1.25	1.27	1.29	1.30	1.35	1.36	25	0.63	0.71
X	Piston	on	1.18	0.98	1.17	0.94	1.15	1.09	20	0.59	0.45
XI	Piston	on	1.26	0.59	1.10	1.07	1.07	1.02	14	0.63	0.43

Only experiment III shows a mean age at all measured locations in occupied zone smaller than the room mean age. In all the other cases, the average age of locations 2 to 6 is equal or higher than the room mean age. As far as the occupied zone is concerned, the piston ventilation is effective only in experiment III.

However, if one looks only at the mannequin, she breathes an air fresher than the room average in experiments II, VIII and XI. These are the experiments with piston ventilation and high air flow rates.



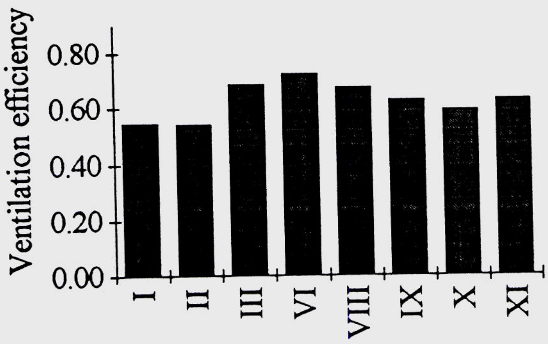


Figure 6: Ventilation efficiencies for the various experiments. At the left, the nominal time constant is calculated from the air flow rate. At the right, the nominal time constant is taken as the age of air at the exhaust.

Figure 6 right shows a predictable pattern: the ventilation efficiency for piston ventilation is higher than this of mixed ventilation. Figure 6 left does not seem to have any meaning. In particular, one case for mixed ventilation has a higher ventilation efficiency than several piston systems. On the right figure, measurement techniques used for both times involved in the calculation of ventilation efficiency (i.e. nominal time constant and room mean age of air) are the same, thus explaining the coherence. These figure seem to show that the air flow rate measured in the ducts was not equal to the air flow rate at the exhaust. Therefore, the reference nominal time constant taken in the present report will be the one measured with tracer technique at the exhaust grilles.

Figure 7 shows clear differences between the various systems. It should be noted, that the measurement accuracy shall be taken into account when comparing the various figures. To be significant, any difference should be larger than the confidence interval. The error in the age of air is about 1 minute, that is 3 to 5 %. The error in the room mean age is similar. Therefore, errors in relative age or in ventilation efficiency is 5 to 10%.

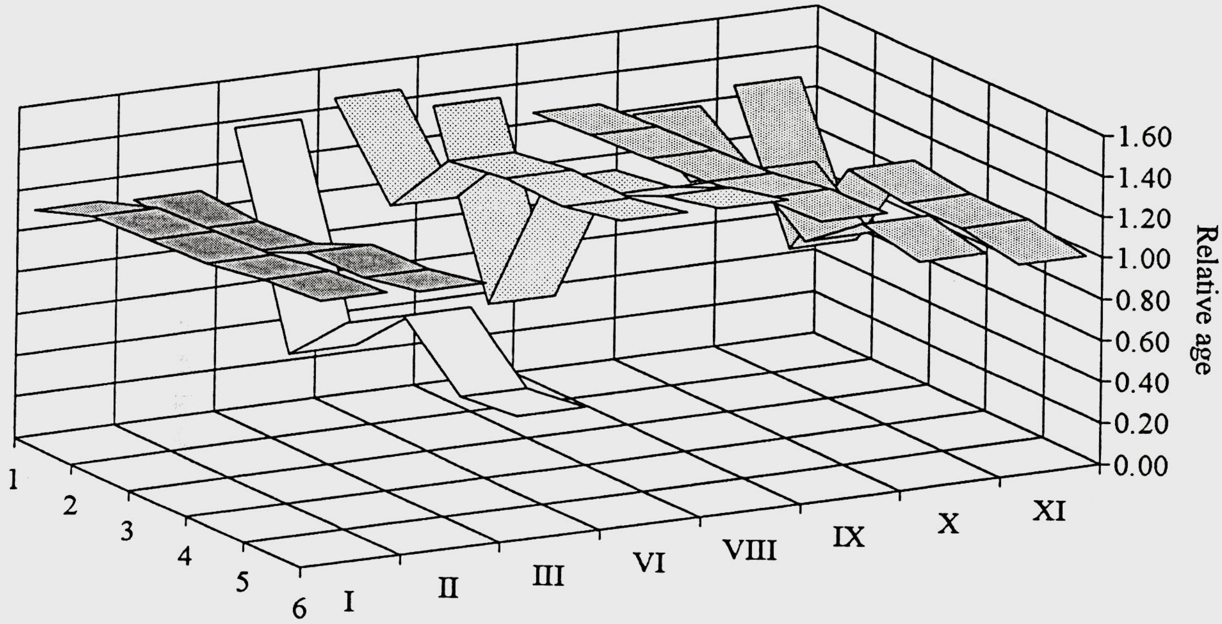


Figure7: Local relative ages (compared to the room mean age) at the measured locations for the various experiments.

When compared to all the other measured systems, system III gives the youngest air to the occupants. This is a piston ventilation system, and the only one without cooling ceiling. Nevertheless, its global efficiency is not better than systems VI and VIII, which are similar but with cooling ceiling on. These systems however, as all the others with cooling ceiling on, present a higher relative age. This shows that, as far as the occupants are concerned, global parameters, like the ventilation efficiency, should be used with care. A global, room averaged parameter provides an averaged information, but does not show local differences, which could be dramatic, as, for example, those observed on figure 7 between case III and cases VI and VIII.

The exhaust presents in all cases, as it should be, a relative age equal or higher than the other places. The youngest air reaches first the mannequin (location 2), then the cylinder 4. That is a surprise, since cylinder 4 is closer to the inlet grilles. Maybe the air takes some time to climb at 1.1 m, where the sampling tubes are. In general, relative differences in the relative age of air in all systems with cooling ceiling are larger when the air flow rate is high (systems VII, XI).

As it could be expected, the mixed ventilation systems (experiments K01, K02, I and II) present a ventilation efficiency close to 0.5 and an homogeneous relative age of air. However, some piston systems do not perform much better. In the systems studied,the cooling ceiling seems to maintain the air at a low level or to mix the air within the room.

3.2. Contaminant removal effectiveness

This effectiveness was measured at the same locations as the age of air, the contaminant source being cylinder 4. This location for a contaminanting person (e.g. a smoker) is the worst one. The complete results of the interpretation of these measurements are given in Annex C, and summarised on Table 9 and Figures 8 and 9.

Basically these measurements were planned to be taken at steady state, after constant injection of tracer gas around cylinder 4. Assuming zero background concentration, the contaminant removal effectiveness is obtained by dividing the tracer gas concentration at the exhaust by the concentration measured at the places of interest.

Table 9: Contaminant removal effectiveness at various locations, when contaminant is coming from cylinder 4, at 1.1 m high. Results in italics are dubious (see annex C)

	Location					Height at location 5 [m]				
	Mannequin	Cylinder	Cylinder	Zone	Zone					
Exp. No	2	3	4	5	6	0.2	0.7	1.1	1.3	1.8
I	0.9	0.7	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
II	1.0	1.0	0.6	1.1	1.1	1.1	1.1	1.0	1.1	1.1
III	1.0	13.6	0.8	2.3	5.1	1.0	1.1	2.2	14.8	1.4
VI	1.1	1.0	0.9	0.9	1.0	2.4	1.2	1.0	0.9	1.0
VIII	*0.6*	*1.2*	*0.8*	*1.1*	*1.1*	1.9	2.2	1.4	1.3	1.3
IX	1.0	1.0	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0
X	1.0	1.1	0.8	1.0	1.0	0.4	0.7	0.9	1.0	1.0
XI	0.6	1.1	0.8	1.0	0.8	0.4	0.4	0.9	0.9	0.9

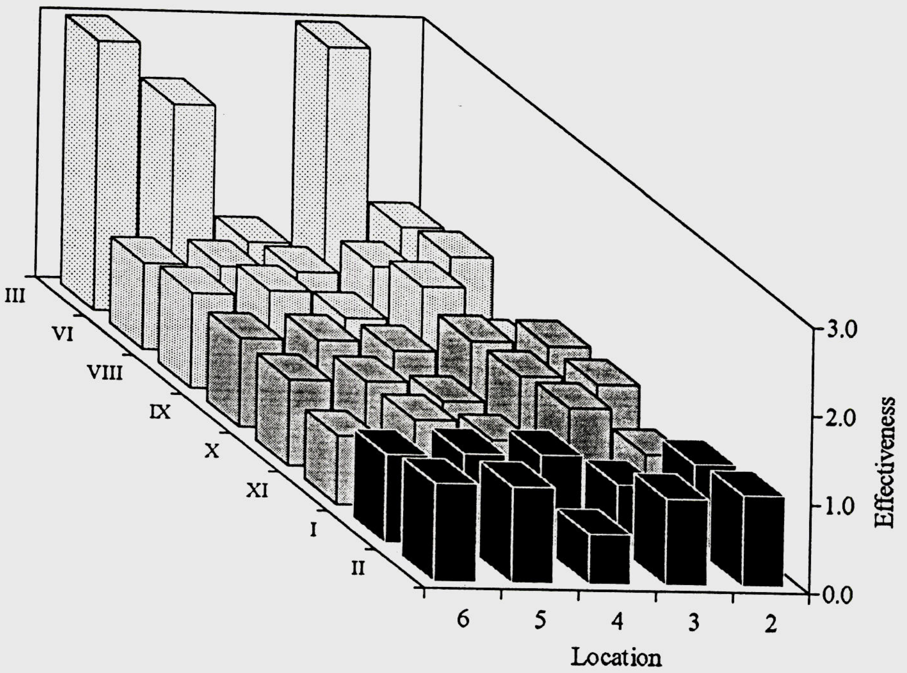
The contaminant removal effectiveness equals to 1 for complete mixing, can be lower if the concentration at location is higher than at the exhaust (bad removal), and higher if the concentration is small.

As it should be, location 4, which is at the contaminant source, presents generally the worse effectiveness. The mannequin, located not far from and downwind cylinder 4, also presents in some case a poor effectiveness. The best place, with regard to that source of contaminant, is at location 3, in the opposite corner of the room.

Here again, system III, without cooling, presents the largest differences. With a few exceptions, all the other systems have a contaminant removal effectiveness close to 1. The exceptions are as well for piston ventilation (in the mannequin, for experiments VIII and XI and for mixed ventilation (systems II and K02 at location 4).

The differences between piston ventilation systems and mixed systems are more obvious on Figure 13, which shows the vertical distribution of the contaminant removal effectiveness at location 5, that is in the vicinity of the mannequin. All the mixed systems have an effectiveness close to one, form floor to ceiling, while most piston ventilation systems show differences. The exception is system IX, with structured cooling ceiling and low air flow rate, which is homogeneous.

Figure 8: Contaminant removal effectiveness at various locations, when contaminant is coming from cylinder 4, at 1.1 m high. Value at locations 6 and 3 for experiment III are out of scale (effective values: 5 and 14)



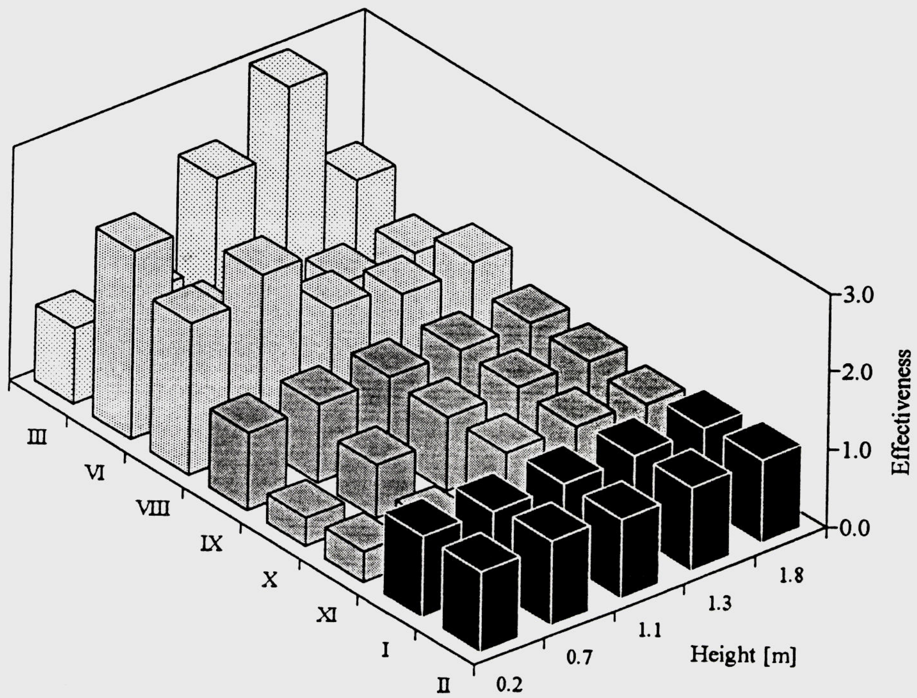


Figure 9: Contaminant removal effectiveness at various heights, at location5, when contaminant is coming from cylinder 4, at 1.1 m high. Value at 1.3 m for experiment III is out of scale (15).

The best figures are obtained in system III, at 1.3 m, and for systems VI and VIII, close to the floor. The worst case, at location 5, is for systems X and XI, close to the floor. However, this level does not need to be well ventilated, since only small pets may breath at that height.

4. CONCLUSIONS

Ages of the air and contaminant removal effectiveness were measured at several locations in a test chamber, for three different ventilation systems (piston type, and two different mixing systems), with and without cooling ceiling (also two different types). The ventilation efficiency is also obtained for each of these cases.

Mixing systems show a very homogeneous pattern, as it was expected. The homogeneity is the highest for large air flow rates. At the same air flow rates, the system with slot inlets does not show significant differences when compared to the vortex inlets.

Piston ventilation system works well when the cooling ceiling is off, or when on, if the specific air flow rate is high (in this case, higher than 3.3/h). The effect of the cooling ceiling is to counteract the upward piston ventilation and to induce a partial mixing.

Among the values tested, the largest air flow rates showed the greatest piston effects, as far as the ages of air or contaminant removal are concerned. The conclusion is changed if the global ventilation efficiency is taken as reference. This shows that this latter parameter should be used with care.

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[2] Sutcliffe, H. C.: **A Guide to Air Change Efficiency**. *AIVC technical note 28, Bracknell, Berkshire RG124AH, GB, 1990. Airbase #4000*

[3] Roulet, C.-A. and Vandaele, L.: **Airflow Patterns Within Buildings - Measurement Techniques.** *AIVC technical note 34, Bracknell, Berkshire RG124AH, GB, 1990.*

[4] Roulet, C.-A. and Cretton, P.: **Field Comparison of Age of Air Measurement Techniques.** *Roomvent'92, Aalborg, 1992.*

[5] Roulet, C.-A., Compagnon, R. and Jakob, M.: **A Simple Method Using Tracer Gas to Identify the Main Air- and Contaminant Paths Within a Room.** *11th AIVC conference, Belgirate, 1990. Airbase #4865.*

[5] Roulet, C.-A. and Cretton, P.: **Age of the Air and Ventilation Efficiency in an Auditorium.** *Seminar "Luftungsforschung für die Praxis", Zürich, 19 Mai 1992.*

ANNEX A: USER INFORMATION FOR COMPUTER CODES

TRANSBK: Translation of Brüel & Kjaer data

Any questions to P. Cretton / C.-A. Roulet
LESO-PB
EPFL
CH - 1015 Lausanne
Switzerland
Phone (+41 21) 45 45
Fax (+41 21) 27 22

Language	QuickBasic 4.5.
System	MS-DOS
Minimum RAM memory	512 K
Graphic environment	no.
Dynamic allocation of memory	no.

Purpose.

TRANSBK reads Brüel & Kjaer time series concentrations output file and translates these concentrations in a new file, which will then be used by NEWAGE program.

Working specifications.

Input file must be a Brüel & Kjaer's (B&K) output file purged of all but the time series concentrations lines and saved as an ASCII file. Any text editor can be used for that pre-treatment.

Procedure.

Running program asks the following questions:

"Brüel & Kjaer's input data file configuration is as follows:"
" - One file for all measurement points. One line for each measurement point."
" - One line is as follows: measurement rank, measurement time (hh:mm:ss),"
" concentration of each gas. A non measured gas result is given by '. . .'
" - Maximum 6 gases and 15 measurement points."
"Is it the right configuration for your input file (Y=1,N=0) ?"

Asks user to verify input file configuration.

"Number of measurement points (max. 15) ?"

Asks for number of spatial measurement points. Must be the same as the number of measurement points in input file.

"Number of tracer gases measured (maximum 6) ?"

Asks for number of tracer gases of interest. Could be less than the number of measured gases of input file.

"Gas transfer delay before analysis (sec.) ?"
"If unknown, put 22 seconds (10m transfer tubes)."

Time at the beginning of each line is B&K clock time for the beginning of one measurement cycle (all gases for one point). According to B&K literature and investigations, one measurement cycle begins by a purging/calibration procedure of some 19 seconds, followed a by delay of ~3 sec./10m necessary to pump gases along the sampling tubes inside the apparatus. So the real time of measurement is

Clock time (read in the file) + 19 sec. + 3 sec/10m = Clock time + delay.

Program asks for a mean delay typical for an average sampling tube length.

"Channel (A-E, W) for the"; "measured gas."

Asks then for the B&K channel corresponding to the different gases (I = 1, then 2, then 3 etc.) until number of gases completion. Order follows user choice, not B&K channel succession. For example, user can choose first gas X (Channel C) and then gas Y (Channel A), ending by gas Z (Channel W). Channel code must be introduced in capital letter.

"Path for input data file ? "

Asks for DOS path (for example C:\Dir_Name\) to input file. If already in the current directory then RETURN.

"Extended name of input data file ? "

E.g. Input.dat.

"Extended name of output file ? "

E.g. Outfile.dat. Output (result) file is created in current directory.

Result.

Result is an output file of maximum 100 lines of 182 numbers (real or integers). Each line covers a global cycle of measurement of 6 gases at 15 measurement points and is as follows:

1) Cycle number (I = 1..100)
2) Time at beginning of cycle = time of measurement of the 1st gas at the 1st point, in seconds.
3) 15 arrays of 12 numbers. One array for each measurement point (N = 1..15). **Order of succession follows the input B&K file order**. Arrays corresponding to non measured points appear after all arrays corresponding to measured points and are filed with zero's. Each array is composed of 6 sub-arrays of 2 numbers. One sub-array for each gas (M = 1..6). **Order of succession follow the user gas introduction order**. Sub-arrays corresponding to non measured gases appear after all sub-arrays corresponding to measured gases and are filed with 0's. Each sub-array is as follows: first measured concentration (B&K unit) , then time (seconds).

User should take note of measurement points and gases succession order for use with **NewAge** program.

B&K input file:

n	hh:mm:ss	Ca Cb...... Cw	↵
n+1	hh:mm:ss	Ca Cb...... Cw	↵
......	......	......	↵
......	......	......	↵
Absent point			↵
n+M	hh:mm:ss	Ca Cb...... Cw	↵
n+M+1	hh:mm:ss	Ca Cb...... Cw	↵
......	......	......	↵
......	......	......	↵

Output file

n	T_n	n	n+1	n+2	......	n+M-1	Absent	Absent	Absent	Absent	↵
n+M	T_{n+M}	n+M	n+M+1	n+M+2	......	n+2M-1	Absent	Absent	Absent	Absent	↵
......	...	......	......	......	......	......	......	......	......	......	↵

That is several lines of 15 arrays each, one for each point. Each array is

C1	T1	C2	T2	C3	T3	...	...	0	0	0	0	0

NEWAGE: Age of Air calculation program

Any questions to	P. Cretton / C.-A. Roulet LESO-PB EPFL CH - 1015 Lausanne	Phone (+41 21) 45 45 Fax (+41 21) 27 22 Switzerland

Language	QuickBasic 4.5.
System	MS-DOS
Minimum RAM memory	1000 K
Graphic environment	no.
Dynamic allocation of memory	yes.

Purpose.

NEWAGE reads time series concentrations from a standard input file and performs Age of Air calculations for as much as 3 different methods (Decay, step-up, Pulse) for 6 gases and 15 measurement points.

Working Specifications.

Input file must be of maximum 100 lines of 182 numbers (real or integers). Each line covers a global cycle of measurement of maximum 6 gases at 15 measurement points and is as follows:

1) Cycle number (I = 1..100)
2) Time at beginning of cycle = time of measurement of the first gas at the first point, in seconds.
3) 15 arrays of 12 numbers. One array for each measurement point (N = 1..15). Arrays corresponding to not measured points appear after all arrays corresponding to measured points and are filed with 0's. Each array is composed of 6 sub-arrays of 2 numbers. One sub-array for each gas (M = 1..6). Sub-arrays corresponding to not measured gases appear after all sub-arrays corresponding to measured gases and are filed with 0's. Each sub-array is as follows: first measured concentration (various unit), then time (seconds).

User should take note of measurement points and gases name and succession order. TRANSBK creates such input files from Brüel & Kjaer files.

Procedure.

Running program asks the following questions:

"Parameter file for your experiment already present (Y=1/N=0) ?"

Asks user if all experiment parameters (response to subsequent questions) is already saved.

If No.

User should first answer questions to define the parameters of the experiment.

"Number of tracer gases (maximum 6) ? "

Must be the same as the number of tracers gases in input file. Basic precautions taken against out of range values.

"Number of measurement points (maximum 15) ? "
Must be the same as the number of measurement points in input file. Basic precautions taken against out of range values.

"Error (sigma) estimated on initial (T0) and final time (Tf) (sec.)? "
Error on injection time (initial time T0) can lead to quite consequent errors in age of air determination, so σ(t) is asked for subsequent error analysis. 5 seconds is a reasonable σ(t) if user clock and analyser clock match (best to use analyser clock, if possible). Error on experiment completion is considered the same (final time Tf). Error in Δt determination between two measurements of the same gas at the same point (apparatus internal clock) is neglected.

"Probability level for confidence interval calculations (%) ?"
Range is from 5% to <100%. A frequently used level is 95%. Basic precautions taken against out of range values (default value is 95%).

Then for each gas the following questions arise. Gas succession order must be the same as in input data file.

"Name of gas number "
E.g. N_2O or Nitrous Oxide.

"Age of air calculation method associated with gas number "
"(Decay=1, Step-Up=2, Pulse=3, None=0)"
Only one method associated with one gas. If more than one experiment has been performed with the same gas, as it is often the case (for example, a step-up then a Decay then another step-up etc.), user should run the program once for each experiment. Use <None> option to ignore gases and shorten calculation time.

"Full range (max.) for concentration measurement of gas "
"If not known or not important, put a negative value. Measured maximum"
"value will be taken as full range. No out of range measurement warnings."
Asks for full range of experimental apparatus for the gas. Must be introduced in the same physical unit than those of the measured gas... If not known or not important put a negative (but be sure the peak concentration of time series is of the order of full range of apparatus !). Concentrations larger than full range are noted as a warning in .BUG result file.

"Background concentration for gas "
"If not known, put a negative value. Minimal concentration between"
"initial and final time will be taken as background concentration."
Self-explanatory. Must be introduced in the same physical unit than those of the measured gas...

"Sigma on concentration measurement is determined as follows:"
*"   Sigma(C(t)) = A * C(t) + B   "*
"   0%<= A <= 20% 0%<= B <= 2%   "
"Choose A value (% of measurement) for gas "
"Choose B value (% of full range) for gas "
σ(C) is asked for subsequent error analysis. To take into account the wide and sometimes unclear range of specifications for experimental errors, a "proportional to signal + noise" model is used for σ(C). Basic precautions taken against absurd (out of range) values. In such cases, A and B are forced to reasonable values (2% A and 0.2% B are typical for of Brüel & Kjaer gas analyser).

"Initial Step of experiment for gas (1 < Step < 100) "
"Will be used if initial time unknown. If unknown put incoherent value."
The "T0 Step" is the Cycle number of input data file. Time at the beginning of the cycle will be used as T0. "Incoherent" = out of defined range.

"Initial time (H, M, S) of experiment for gas "
"If unknown put incoherent values. Initial step will be used as initial time."

"Hour "
"Minute "
"Second "

As said, T0 is the injection time of the gas. "Incoherent" = negative (h, m, s) or > 23 (H) or > 59 (m, s).

"Final Step of experiment for gas (1 < Step < 100) "
"Will be used if final time unknown. If unknown put value 100."
The "Tf Step". Any incoherent value (out-of-range, Step(Tf) < Step(T0) + 10) will force "Tf Step" to last Cycle number of time series.
"Final time (h, m, s) of experiment for gas "
"If unknown put incoherent values. Final step of experiment will be used as initial time."
"Hour "
"Minute "
"Second "

Tf is the time when the user consider that the experiment is completed. There must be a minimum of 10 measurement cycles between final time Tf and initial time T0. If not or if Tf incoherent, Tf is forced to final cycle time (Tf Step = 100). "Incoherent" = negative (H, M, S) or > 23 (H) or > 59 (M, S).

Then the following question.

" All gases measured at the same spatial points (Y=1/N=0) ?"

Necessary, because the user can change experiment configuration between two gas injections. Whichever the answer, then for each spatial points the following questions arise. Spatial point succession order must be the same as in input data file.

"Name of Point number "; J

If all gases are measured at same spatial points, name will be independent of gas.

"Status (position) of Point number "; J
"(Inside Room =1, Room Exhaust =2, Outside Room =3, Unknown=0)"

If all gases are measured at same spatial point, Status will be independent of gas. Use <Unknown> option to ignore points and shorten calculation time.

Then the last question of experiment parameters part. A "yes" answer is strongly recommended...

"Do you want to save this parameters in a file (Y=1,N=0) ?"

If Yes. Two questions, then return to main procedure.

"Path for output parameter file ?"

Asks for DOS path (for example C:\Dir_Name\) for parameter file. If user want it in the current directory then RETURN.

"Extended name of output parameter file ? "

E.g. Param.Par.

If No, nothing happens..., return to main procedure.

If Yes.

User can use existent parameter file or a parameter file derived from an existent one (through any good text editor, saving the new parameter file as ASCII. See parameter file description). Procedure is then straightforward and then returns to main procedure.

"Path for input parameter file ?"

Asks for DOS path (for example C:\Dir_Name\) for parameter file. If already in the current directory then RETURN.

"Extended name of input parameter file ? "

E.g. Param.Par.

Once experiment parameters is known, whichever the way, user is back to the main procedure.

"Path for input data file ?"

Asks for DOS path (for example C:\Dir_Name\) for input data file. If already in the current directory then RETURN.

"Extended name of result text file ? "
"-> Another file with same name and .XEL extension will be "
" created for use in a spreadsheet. "
"-> Another file with same name and .BUG extension will be "
" created for verification and tracking. "

Self-explaining. Output (result) files are created in current directory.

Result.

3 Files, all ASCII:

1) User_Name.User_Extension file.
Contains Local Ages and final decay time constants at Inside and Outside spatial measurement points, Room Mean Age, Nominal Time constant and final decay time constant at Exhaust points, Spatial Room Mean Age and Spatial Mean final decay time constants (if significant) averaged on Inside points. All results are provided with confidence interval according to level and error parameters chosen.

2) User_Name.XEL
Devised for use with a spreadsheet. One line = one measurement point and is as follows: G + gas number + gas Name, P + Point number + Point Name, Local Age (Nominal Time for Exhaust) + Confidence interval, Room Mean Age + Confidence Interval (if not an Exhaust point, then 0's).

3) User_Name.BUG
Gives some other useful information about mathematical procedures and choices, decay fitting, error optimisation, concentrations warnings etc. Useful to track singularities, strange results or computation troubles. Awareness of age of air calculation theory is necessary for a good comprehension.

Parameter File Example

Source: Parameter File P104-3.PAR for experiment file EK104-3. from Sulzer ventilation effectiveness experiment program. The file is for a step-up experiment with SF_6 gas injected in the inlet and 6 measurement points. One measurement point is the exhaust. Background SF_6 concentration (supposed to be close to 0) considered as unknown (e.g. minimal of time series will be taken as background concentration). Experimental measurement error estimated for a Brüel & Kjaer gas monitor system.

File content	Comments.	
1	Number of tracer gases.	
6	Number of measurement points.	
5	$\sigma(t)$	[sec.]
95	Confidence interval level	[%]
SF6	Name of gas 1.	
2	Method associated to gas 1 (2: step-up)	
-1	Full range for gas: 1 (with such a value user assumes that all measurement are within experimental range and that the maximum measured value is of the order of full range.)	[ppb in this case]
-1	Background concentration for gas: 1 (-1 => not known)	[ppb in this case]
2	A value of $\sigma(C) = A*C + B$ concentration error model	[ppb in this case]
0.2	B value of $\sigma(C) = A*C + B$ concentration error model	[ppb in this case]
1	T0 Step (first Cycle).	
11	T0 time, hour.	
54	T0 time, minute.	
49	T0 time, second. (If T0 time is coherent, it has priority on T0 step, even if it appears that the two resultant time values aren't coherent together. A program can't be better as his user.)	
-1	Tf Step (incoherent value).	
-1	Tf time, hour (incoherent value).	
-1	Tf time, minute (incoherent value).	
-1	Tf time, second (incoherent value). (Here, user decide he don't know Tf Step and Tf time, so he let the program push the Tf Step to the last Step of time series, e.g. Tf Time also).	
Exhaust 1	Name of measurement point 1 for gas 1.	
2	Status of measurement point 1 for gas 1 (an exhaust point).	
1	**Internal to program** (user doesn't have to introduce). T0 status on the basis of former answers (1: further calculations. 0: measurement point ignored).	
Mannequin 2	Name of measurement point 2 for gas 1.	
1	Status of measurement point 2 for gas 1 (an inside point).	

1	**Internal to program** (user doesn't have to introduce). T0 status on the basis of former answers (1: further calculations. 0: measurement point ignored).
Heated Cylinder 3	Name of measurement point 3 for gas 1.
1	Status of measurement point 3 for gas 1 (an inside point).
1	**Internal to program** (user doesn't have to introduce). T0 status on the basis of former answers (1: further calculations. 0: measurement point ignored).
Heated Cylinder 4	Name of measurement point 4 for gas 1.
1	Status of measurement point 4 for gas 1 (an inside point).
1	**Internal to program** (user doesn't have to introduce). T0 status on the basis of former answers (1: further calculations. 0: measurement point ignored).
Outside Flow 5	Name of measurement point 5 for gas 1.
1	Status of measurement point 5 for gas 1 (an inside point).
1	**Internal to program** (user doesn't have to introduce). T0 status on the basis of former answers (1: further calculations. 0: measurement point ignored).
Occupied Zone 6	Name of measurement point 6 for gas 1.
1	Status of measurement point 6 for gas 1 (an inside point).
1	**Internal to program** (user doesn't have to introduce). T0 status on the basis of former answers (1: further calculations. 0: measurement point ignored).

[EOF]

Strange Result Example

This example shows one of the strange results that can arise for age of air calculation by automatic interpretation of a time series by NEWAGE. It shows that the user has anyway the duty to examine carefully the results and illustrate the utility of .BUG file in this case.

The example is selected from a N_2O Pulse experiment in an auditorium with a priori good mixing conditions. Ground N_2O concentration (order of 50 ppm due to water vapour interference, supposed constant) is considered as unknown (e.g. minimal of time series will be taken as ground concentration). There are 11 measurement points and at a first glance the overall result are coherent, but...

A more careful examination of User_Name.User_Extension file:

```
Point: 9 Name:huit
Point defined as Inside
T0 present and between measurement step 1 and 2.
Local Age      : 1756.546  +/-  239.486
Best Local Tau : 1508.557  +/-  356.1845
```

Point: 10 Name:neuf
Point defined as Inside
T0 present and between measurement step 1 and 2.
Local Age   : 4056.798 +/- 3114.542
Best Local Tau :-5548.404 +/- 10354.9

```
Point: 11 Name:dix
Point defined as Inside
T0 present and between measurement step 1 and 2.
Local Age      : 1598.958  +/-  300.9099
```

Best Local Tau : 1544.484 +/- 526.7491

reveals that point 10 shows quite different results. Local age isn't coherent with values of other measurement points, apparently invalidating good mixing hypothesis. Best local tau does not seem physical (it indicates a growth of the concentration !) and confidence intervals are much too large. An examination of .BUG file reveals that maximal measured value is only ~5 ppb above minimal one. The experimental end value (step 36) is some 2 ppb above the minimal value, e.g. ~40% of experimental range. The next smaller value arise at Step 23 and is worth ~15% of experimental range.

Gas 1 Point 10
****

Before normalisation

Step	C(step)	T(step)
1	*57.44*	*29820*
2	60.76	30150
3	62.61	30480
4	*62.88*	*30810*
5	62.32	31140
6	61.94	31470
7	61.91	31800
8	60.59	32130
9	60.3	32460
10	60.66	32790
11	60.44	33120
12	60.38	33450
13	60.23	33780
14	60.1	34110
15	60.09	34440
16	60.05	34770
17	60.04	35100
18	59.95	35430
19	59.92	35760
20	59.92	36090
21	60.25	36420
22	60.44	36750
23	*58.18*	*37080*
24	58.34	37410
25	59.21	37740
26	59.57	38070
27	59.53	38400
28	59.56	38730
29	59.58	39060
30	59.48	39390
31	59.07	39720
32	59.45	40050
33	59.15	40380
34	59.44	40710
35	*59.64*	*41040*
36	*59.8*	*41370*

No user defined ground value for concentration measurement of gas 1
Minimal value taken as background concentration.
Gas 1 Point 10 Min and maximum before normalisation.
Minimum: 57.44 at measurement step 1
Maximum: 62.88 at measurement step 4
After normalisation C T0: 5.548126E-02 at T0: 0 interpolated between:
0 at -30 sec. left, measurement step 1
.6102938 at 300 sec. right, measurement step 2
Normalised noise level 2 % of experimental range.
Now C(t),T(t) at step 1 changed to 5.548126E-02 0

After 0-1 normalisation, data presents itself as follows:
After normalisation. Gas 1 Point 10 Begins
Integration at step 1

Step	C(step)	T(step)
1.00	*0.06*	*0.00*
2.00	0.61	300.00
3.00	0.95	630.00
4.00	*1.00*	*960.00*
5.00	0.90	1290.00
6.00	0.83	1620.00
7.00	0.82	1950.00
8.00	0.58	2280.00
9.00	0.53	2610.00
10.00	0.59	2940.00
11.00	0.55	3270.00
12.00	0.54	3600.00
13.00	0.51	3930.00
14.00	0.49	4260.00
15.00	0.49	4590.00
16.00	0.48	4920.00
17.00	0.48	5250.00
18.00	0.46	5580.00
19.00	0.46	5910.00
20.00	0.46	6240.00
21.00	0.52	6570.00
22.00	0.55	6900.00
23.00	*0.14*	*7230.00*
24.00	0.17	7560.00
25.00	0.33	7890.00
26.00	0.39	8220.00
27.00	0.38	8550.00
28.00	0.39	8880.00
29.00	0.39	9210.00
30.00	0.38	9540.00

Begin Tau fitting and error optimisation from 31
End Tau fitting and residual area calculated at 35

31.00	0.30	9870.00
32.00	0.37	10200.00
33.00	0.31	10530.00
34.00	0.37	10860.00
35.00	*0.40*	*11190.00*

By examination of user parameter file it appears that the user's choice for full range is "-1". So the user decides that **current** experimental range (C_max - C_ground) is to be used as full range for noise level determination, e.g. 2% of full range in this case (user error parameters for the apparatus: A=0, B=2). This "-1" choice is justified by a previous estimation about the N_2O volume amount to be released to give a peak pulse concentration of ~200 ppb magnitude order (the apparatus full range), which is attained on the other measurement points but as we see, not at this one, where we can see that there is no "real" (experimentally significant) pulse. So this choice drives the program, which fails to find a 2σ (4%) noise-magnitude order measurement in the 0-1 normalised data, to select **all the time series** for age of air integration and fitting optimisation.

Point 10 Gas 1
Npoints fit 5 C(T0) fit 5.230521E-02 *Tau fit -5548.404* T(Ttau) 9870
C end fit .3930325 *Residual area fit -2180.703*
Sigma Tau 3256.338 Half-Confidence 10354.9
Sigma Residual Area 2547.516 Half-Confidence 8100.902

Simpson C 5612.643 Simpson C + Residual Area C 3431.94
Simpson TC 2.622533E+07 Simpson TC + Residual Area TC 1.392269E+07
Simpson T^2C 1.807624E+11 Simpson T^2C + Residual Area T^2C 4.422341E+10

It has the following results:

- Simpson integration is roughly equivalent to integrating a constant concentration on the time series. Result: a ~5500 sec. age of air determination without taking the residual area into account (other points ~1500 sec.) !
- Fitting optimisation procedure (which optimises the residual area confidence interval and not only exponential decay fitting) gives physically "incoherent" results: a negative best local tau, which is really the "best" by the optimisation point of view, and exceedingly large confidence intervals due to "flatness fitting" and the great dispersion of data around this flatness.

If full range user's choice is 200 [ppb] (the instrument full range) instead of "-1", the full scale effect described will be avoided, but most of the concentration measured will be of noise magnitude order, in fact what they really are. It means that the time series will be cut sooner, but the problems arising from "flatness fitting" **won't disappear**, with results perhaps no less strange than before (for instance, age of air of 10^5 sec. due to huge positive best local tau). Nowadays, huge confidence interval will remain. Program is not faulty here: the absence of pulse at this measurement point has still to be explained.

ANNEX B: COMPLETE RESULTS OF AGE OF AIR MEASUREMENTS

The results are provided in the chronological order. Ages of air are in seconds. The confidence intervals are given at 95 % probability.

File EK***-3	Type	Test	Place	Name	Local mean age [s]	±	Room mean age [s]	±
I	4 Vortex grids with closed cooling ceiling							
113	13	1	1	Exhaust 1	1075	52	984	30
113	13	1	2	Mannequin 2	1171	56		
113	13	1	3	Heated Cylinder 3	1183	57		
413	13	4	4	Heated Cylinder 4	1194	57		
413	13	4	5	Outside Flow 5	1244	61		
413	13	4	6	Occupied Zone 6	1270	60		
II	Slot grid with closed cooling ceiling							
116	16	1	1	Exhaust 1	1311	62	1213	37
116	16	1	2	Mannequin 2	1285	62		
116	16	1	3	Heated Cylinder 3	1306	63		
416	16	4	4	Heated Cylinder 4	1456	71		
416	16	4	5	Outside Flow 5	1468	71		
416	16	4	6	Occupied Zone 6	1541	77		
III	Piston ventilation without cooling ceiling							
105	5	1	1	Exhaust 1	1347	64	986	26
105	5	1	2	Mannequin 2	389	28		
105	5	1	3	Heated Cylinder 3	664	40		
405	5	4	4	Heated Cylinder 4	824	53		
405	5	4	5	Outside Flow 5	565	59		
405	5	4	6	Occupied Zone 6	599	35		

File EK***-3	Type	Test	Place	Name	Local mean age [s]	±	Room mean age [s]	±
VI	Piston ventilation with closed cooling ceiling							
104	4	1	1	Exhaust 1	2035	99	1408	34
104	4	1	2	Mannequin 2	1479	79		
104	4	1	3	Heated Cylinder 3	1971	96		
104	4	1	4	Heated Cylinder 4	2033	114		
104	4	1	5	Outside Flow 5	2019	99		
104	4	1	6	Occupied Zone 6	2100	103		
VII	Piston ventilation with closed cooling ceiling							
503	3	5	1	Exhaust 1	1002	49	745	21
503	3	5	2	Mannequin 2	380	119		
503	3	5	3	Heated Cylinder 3	932	49		
403	3	4	4	Heated Cylinder 4	967	74		
403	3	4	5	Outside Flow 5	1060	53		
403	3	4	6	Occupied Zone 6	1111	54		

File EK***-3	Type	Test	Place	Name	Local mean age [s]	±	Room mean age [s]	±
IX	Piston ventilation with structured cooling ceiling							
124	24	1	1	Exhaust 1	1864	93	1490	67
124	24	1	2	Mannequin 2	1895	99		
124	24	1	3	Heated Cylinder 3	1917	104		
124	24	1	4	Heated Cylinder 4	1940	109		
124	24	1	5	Outside Flow 5	2009	131		
124	24	1	6	Occupied Zone 6	2027	99		
X	Piston ventilation with structured cooling ceiling							
123	23	1	1	Exhaust 1	1407	67	1193	40
123	23	1	2	Mannequin 2	1168	58		
123	23	1	3	Heated Cylinder 3	1391	67		
423	23	4	4	Heated Cylinder 4	1124	140		
423	23	4	5	Outside Flow 5	1377	69		
423	23	4	6	Occupied Zone 6	1306	81		
XI	Piston ventilation with structured cooling ceiling							
127	27	1	1	Exhaust 1	1055	52	839	27
127	27	1	2	Mannequin 2	492	44		
127	27	1	3	Heated Cylinder 3	927	55		
427	27	4	4	Heated Cylinder 4	895	171		
427	27	4	5	Outside Flow 5	897	48		
427	27	4	6	Occupied Zone 6	853	49		

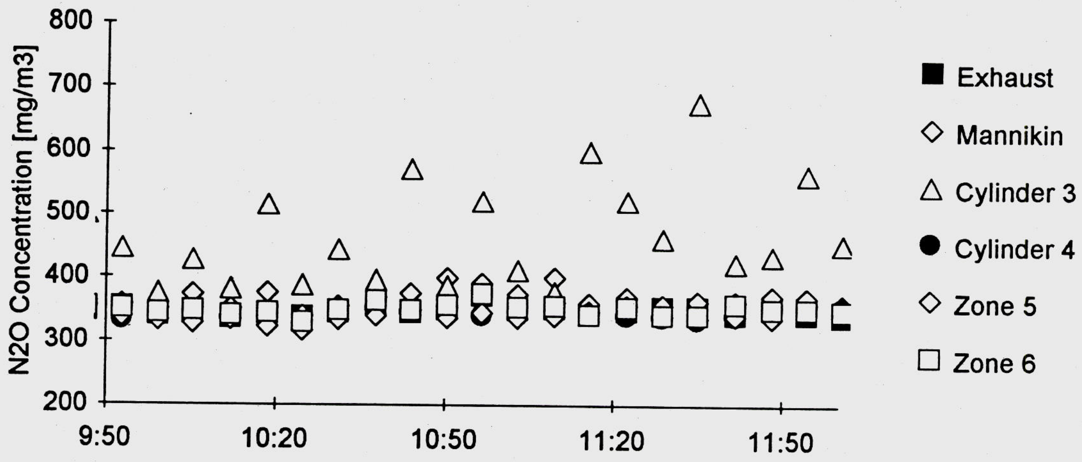
ANNEX C: RESULTS FROM MEASUREMENTS OF CONTAMINANT REMOVAL EFFECTIVENESS.

For each case, a couple of sheets is given. The first one treats the measurements at the locations 1 to 6, and the second sheet shows the results at location 5, for various heights.

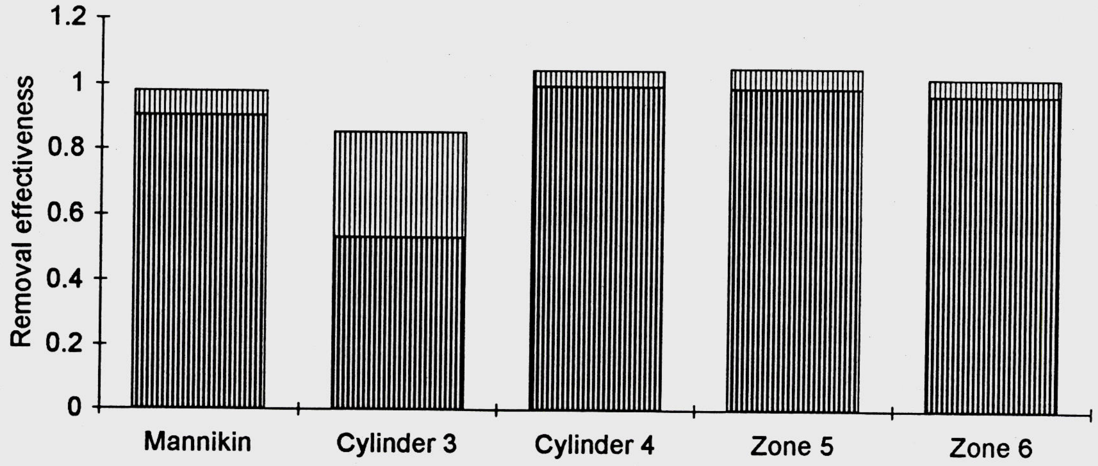
On each sheet, you find first a short description of the test, then a graph showing the concentrations measured at the various locations versus time. A table shows the average of these concentrations, together with 95% confidence interval, and the corresponding removal effectiveness. These are also illustrated in a bar graph, in which the lighter part shows the confidence interval.

A short comment is added in most cases. For some cases, in which measurements show some bugs, longer comments explain how these were interpreted.

File EK213-3.	**4 Vortex inlets with closed cooling ceiling**		
Sampling Tube Length	16.00 m		
Air Pressure	101.33 kPa	Internal load	3155 W
Normalization Temperature	22		60.0 W/m²
Start Time	1992-03-13 09:46	Air flow rate	526 m3/h
Stop Time	1992-03-13 13:09		3.3 /h
Number of Samples	191	Probability for confidence	0.95

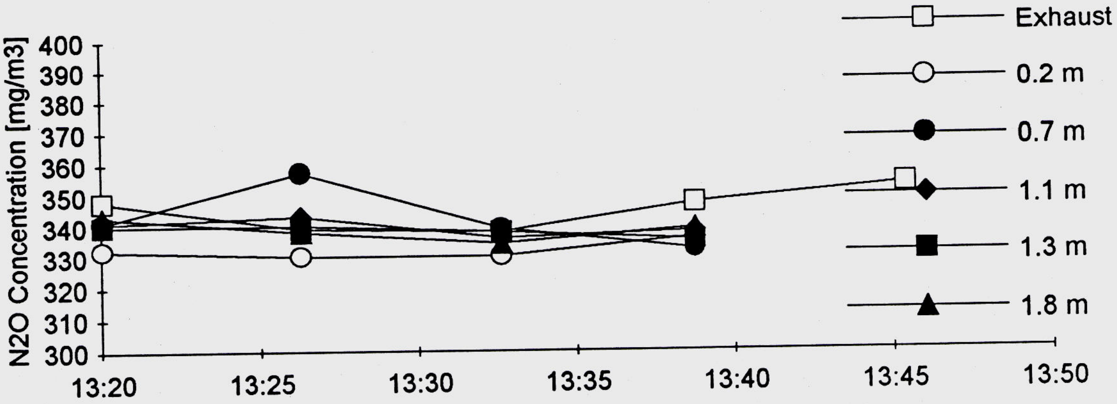


	Exhaust	Mannikin	Cylinder 3	Cylinder 4	Zone 5	Zone 6
Average	348	369	500	341	340	349
Conf. Int.	6	13	115	6	8	7
Removal Effectiveness		0.94	0.69	1.02	1.02	1.00
Confidence Interval		0.04	0.16	0.02	0.03	0.03

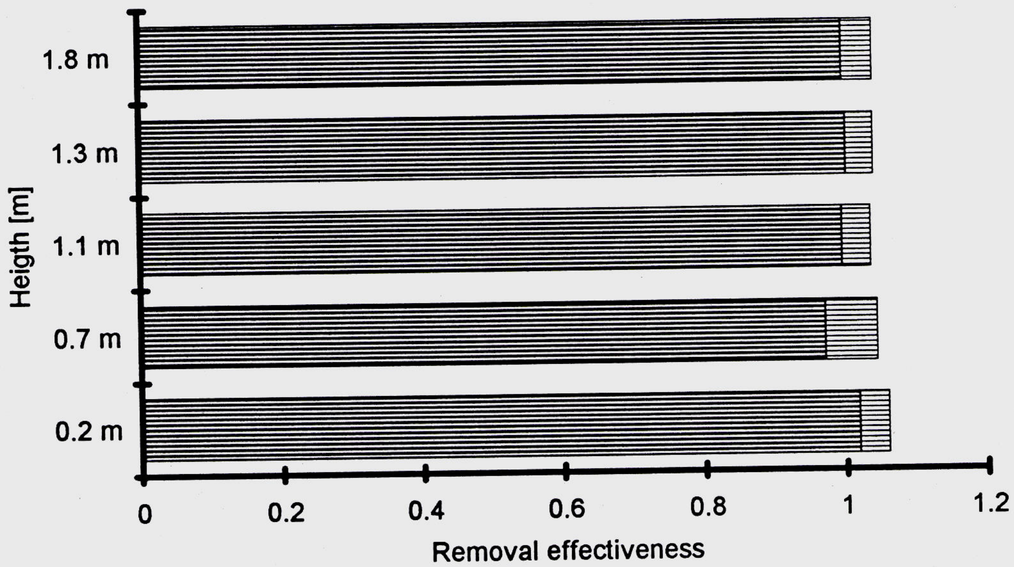


File EK 311-3 **4 Vortex inlets with closed cooling ceiling**

Start Time	1992-03-13 19:46
Stop Time	1992-03-13:45:25
Number of Samples	25



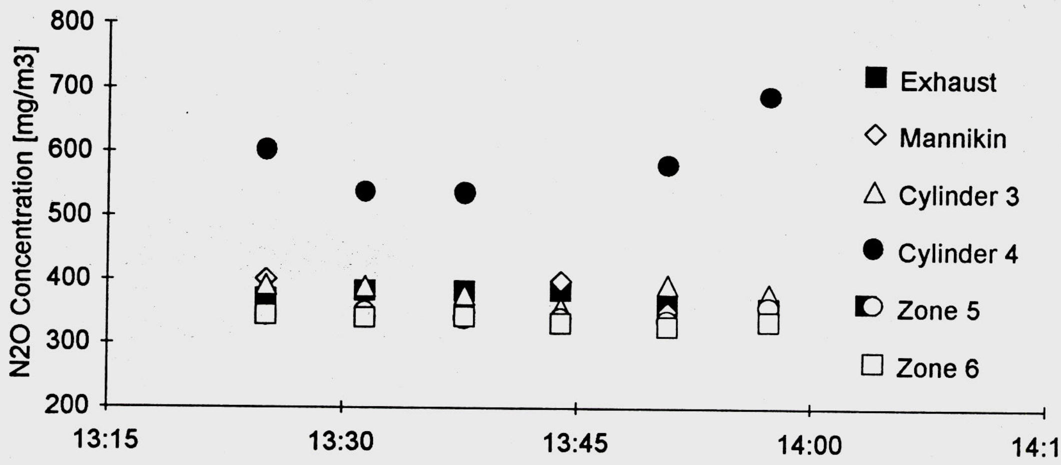
hh:mm	Exhaust	0.2 m	0.7 m	1.1 m	1.3 m	1.8 m
Average	345	332	342	340	338	339
Conf. Int.	6	3	11	3	2	4
Removal Effectiveness		1.04	1.01	1.02	1.02	1.02
Confidence Interval		0.02	0.04	0.02	0.02	0.02



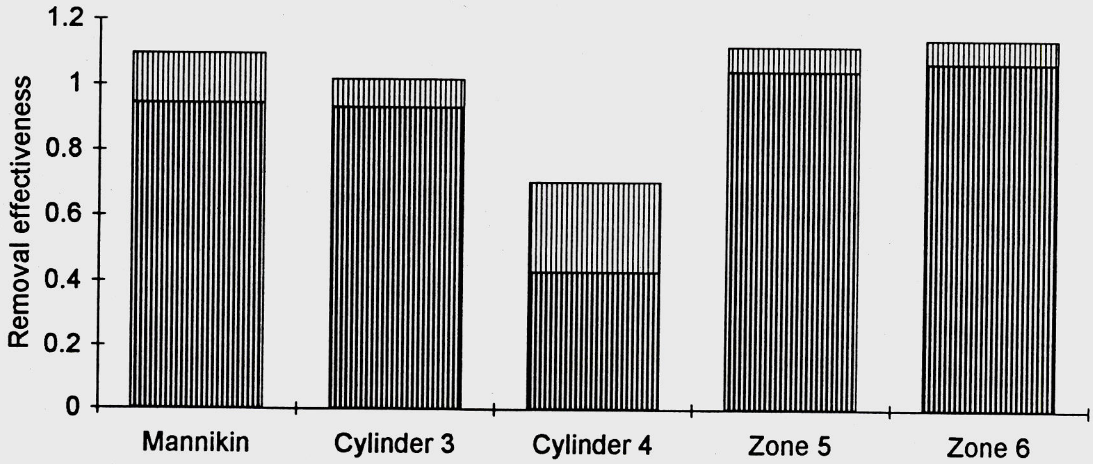
Strong mixing: Except for mannikin and cylinder 3, the differences in removal effectiveness between the various locations do not significantly differ from 1.

File EK216-3 **Slot inlets with closed cooling ceiling** II

Sampling Tube Length	16.00 m		
Air Pressure	101.33 kPa	Internal load	3155 W
Normalization Temperature	22 C		60.0 W/m²
Start Time	1992-03-16 13:24	Air flow rate	526 m3/h
Stop Time	1992-03-16 14:04		3.3 /h
Number of Samples	37	Probability for confidence	0.95

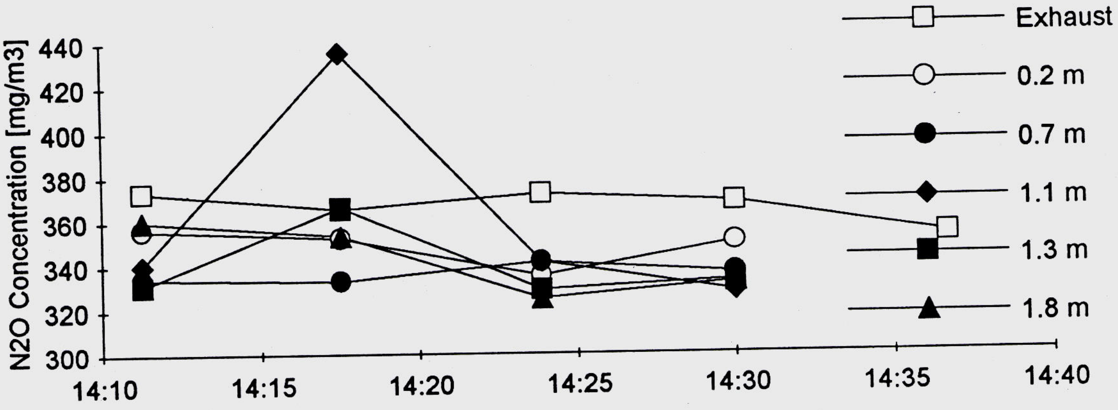


	Exhaust	Mannikin	Cylinder 3	Cylinder 4	Zone 5	Zone 6
Average	372	365	382	655	344	337
Conf. Int.	10	25	13	158	8	6
Removal Effectiveness		1.02	0.97	0.57	1.08	1.10
Confidence Interval		0.08	0.04	0.14	0.04	0.04

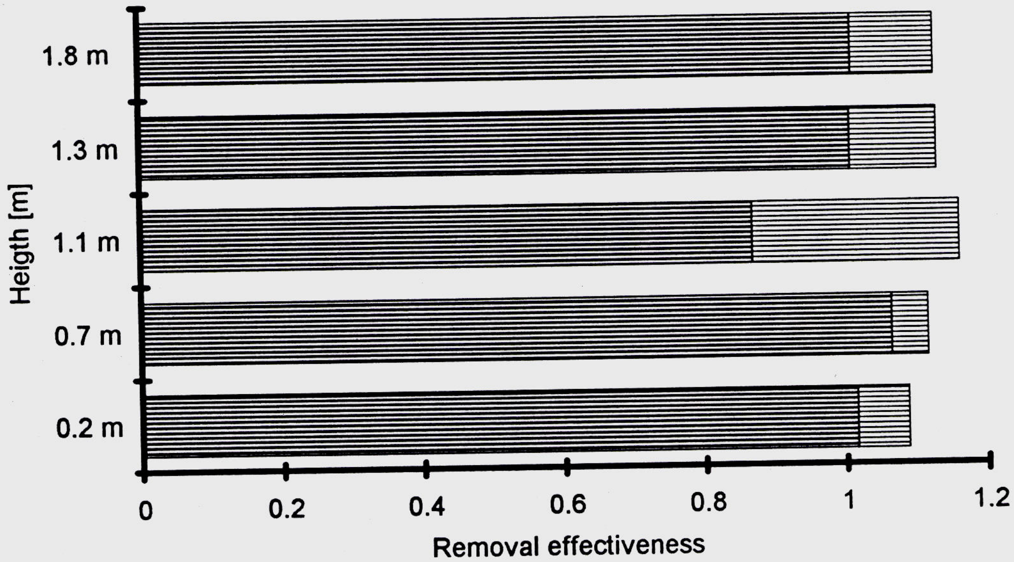


File EK 316-3 **Slot inlets with closed cooling ceiling** **II**

Start Time	1992-03-16 14:10
Stop Time	1992-03-16 14:37
Number of Samples	25



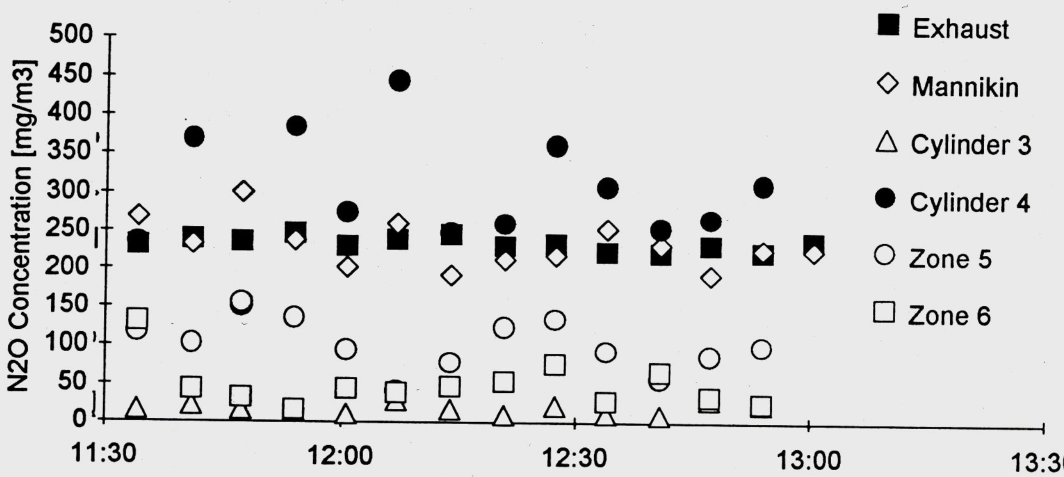
hh:mm	Exhaust	0.2 m	0.7 m	1.1 m	1.3 m	1.8 m
Average	366	348	336	361	343	343
Conf. Int.	8	10	4	51	18	17
Removal Effectiveness		1.05	1.09	1.01	1.07	1.07
Confidence Interval		0.04	0.03	0.15	0.06	0.06



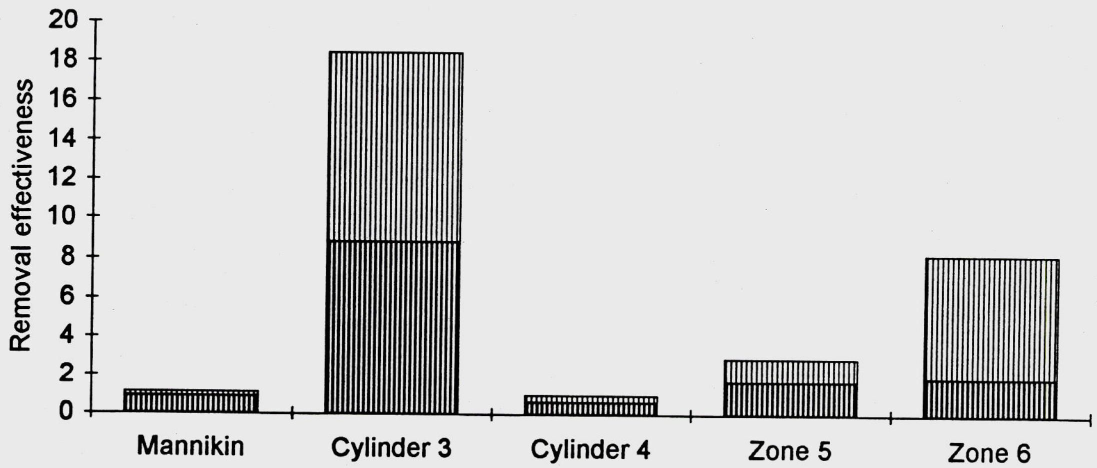
Strong mixing: Except for cylinder 4, the differences in removal effectiveness between the various locations do not significantly differ from 1.

File EK205-3 **Piston ventilation without cooling ceiling** III

Sampling Tube Length	16.00 m		
Air Pressure	101.33 kPa	Internal load	1052 W
Normalization Temperature	22.0 °C		20.0 W/m²
Start Time	: 1992-03-06 10:47	Air flow rate	520 m3/h
Stop Time	: 1992-03-06 13:02		3.3 /h
Number of Recorded Samples	: 122	Probability for confidence	0.95



	Exhaust	Mannikin	Cylinder 3	Cylinder 4	Zone 5	Zone 6
Average	237	237	17	296	102	46
Conf. Interval	8	29	6	63	27	29
Removal Effectiveness		1.00	13.64	0.80	2.32	5.10
Confidence Interval		0.13	4.80	0.17	0.61	3.17



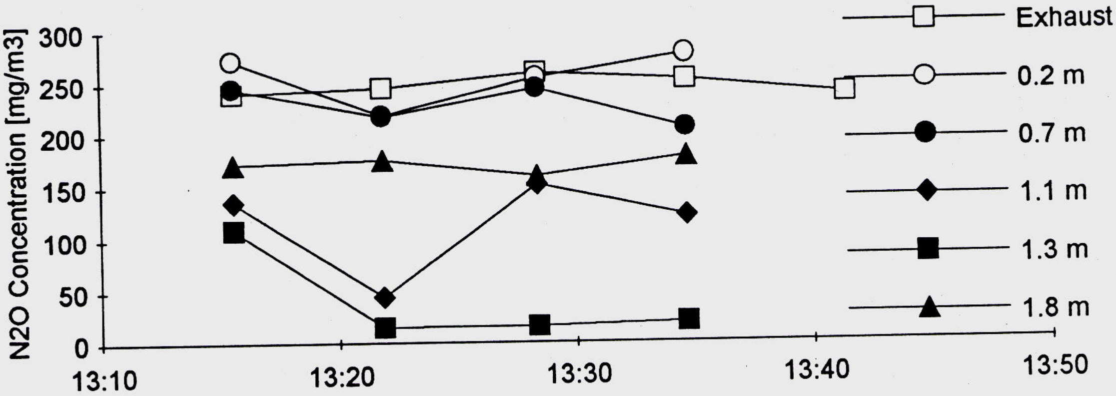
File EK 305-3 **Piston ventilation without cooling ceiling**

1302 Measurement Data ------- 1523936/2526 - 1992-03-06 13:42

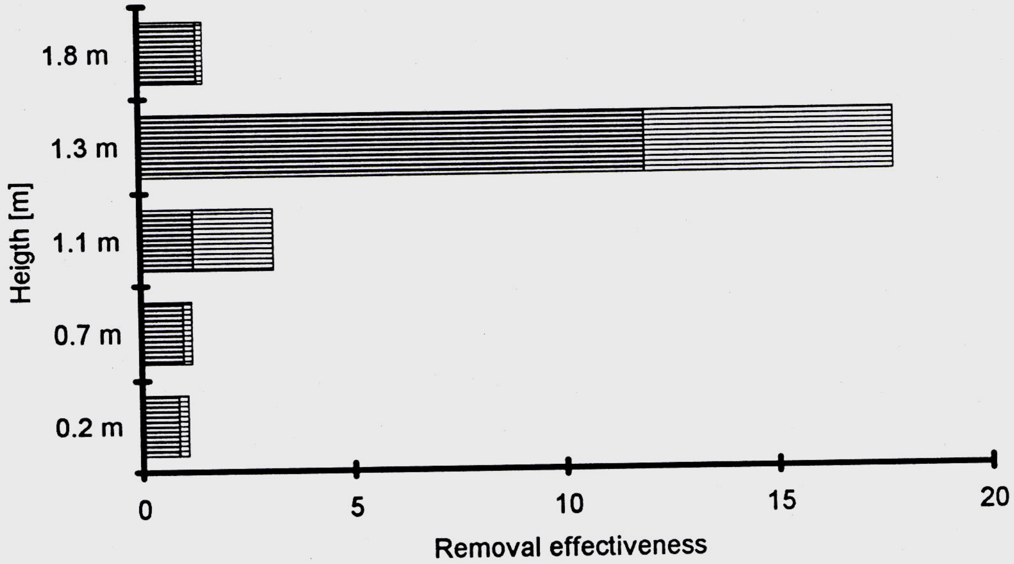
Start Time 1992-03-06 13:15

Stop Time 1992-03-06 13:42

Number of Samples 25

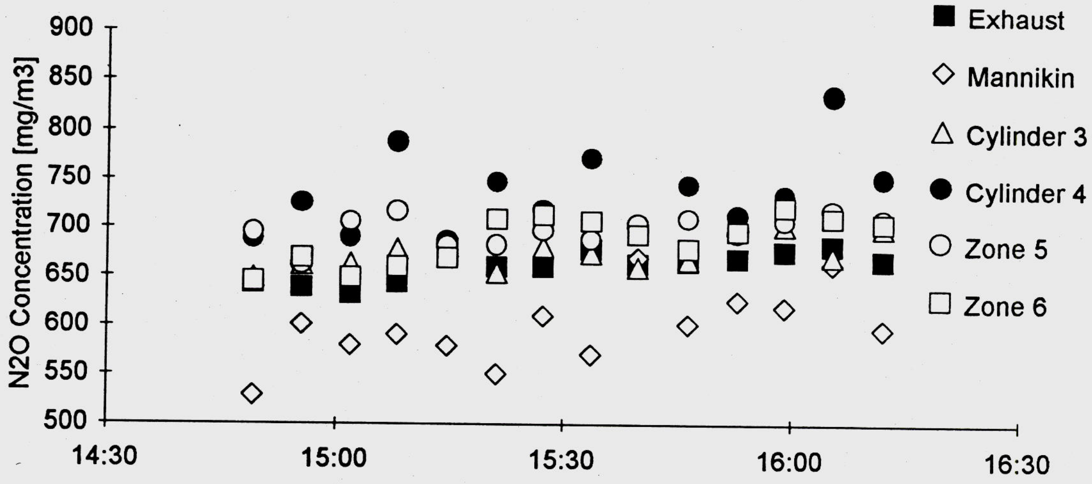


	Exhaust	0.2 m	0.7 m	1.1 m	1.3 m	1.8 m
Average	247	255	228	113	17	171
Conf. Interval	9	27	21	49	3	8
Removal Effectiveness		0.97	1.08	2.18	14.83	1.45
Confidence Interval		0.11	0.11	0.95	2.93	0.09

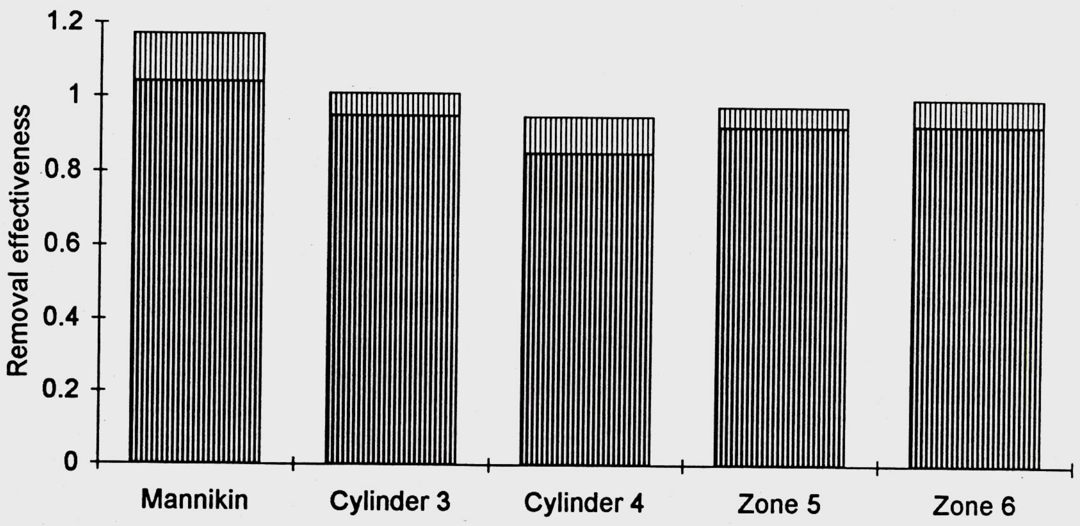


Note that measurements at 1.1 and 1.3 m present strong variations. Result for 1.3 m does not take the first measurement into account.

File EK204-3	**Piston ventilation with closed cooling ceiling**			**VI**
Sampling Tube Length:	16.00 m			
Air Pressure:	101.33 kPa	Internal load	3155 W	
Normalization Temperature:	22°C		60.0 W/m²	
Start Time	1992-03-05 14:48	Air flow rate	268 m3/h	
Stop Time	1992-03-05 16:18		1.7 /h	
Number of Samples	85	Probability for confidence		0.95

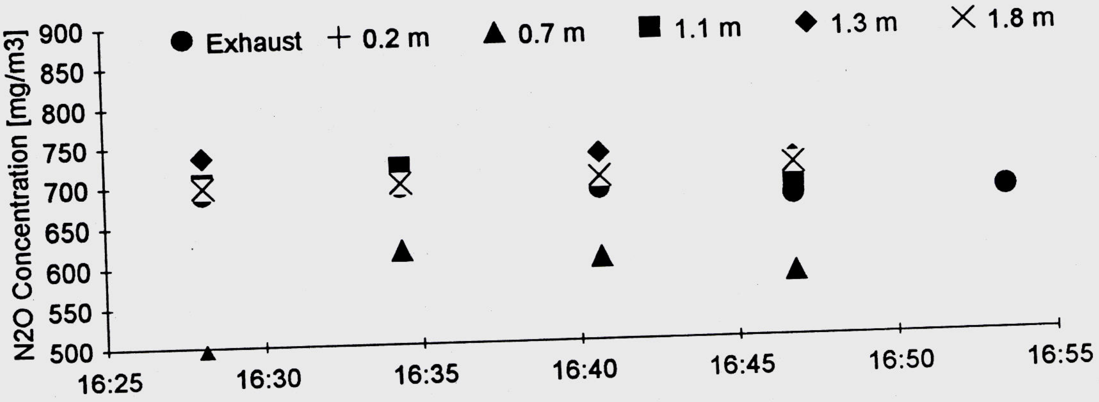


N2 O mg/m3	Exhaust	Mannikin	Cylinder 3	Cylinder 4	Zone 5	Zone 6
Average	662	599	675	736	698	688
Conf. Interval	14	33	16	37	14	22
Removal Effectiveness		1.10	0.98	0.90	0.95	0.96
Confidence Interval		0.07	0.03	0.05	0.03	0.04

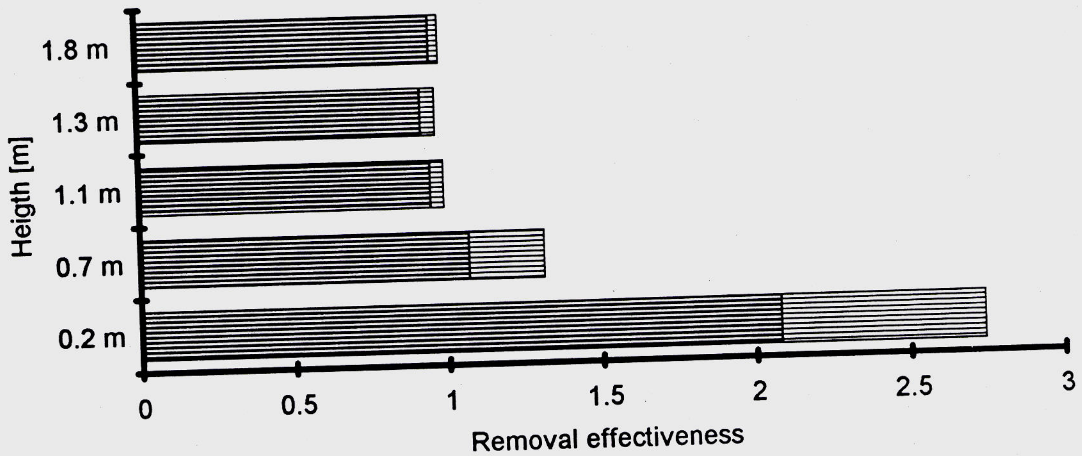


File EK304-3 **Piston ventilation with closed cooling ceiling** **VI**

Start Time : 1992-03-05 16:27
Stop Time: 1992-03-05 16:54



hh:mm:ss	Exhaust	0.2 m	0.7 m	1.1 m	1.3 m	1.8 m
Average	683	283	573	703	722	703
Conf. Inerval	8	39	58	13	17	7
Removal Effectiveness		2.41	1.19	0.97	0.95	0.97
Confidence Interval		0.33	0.12	0.02	0.02	0.02

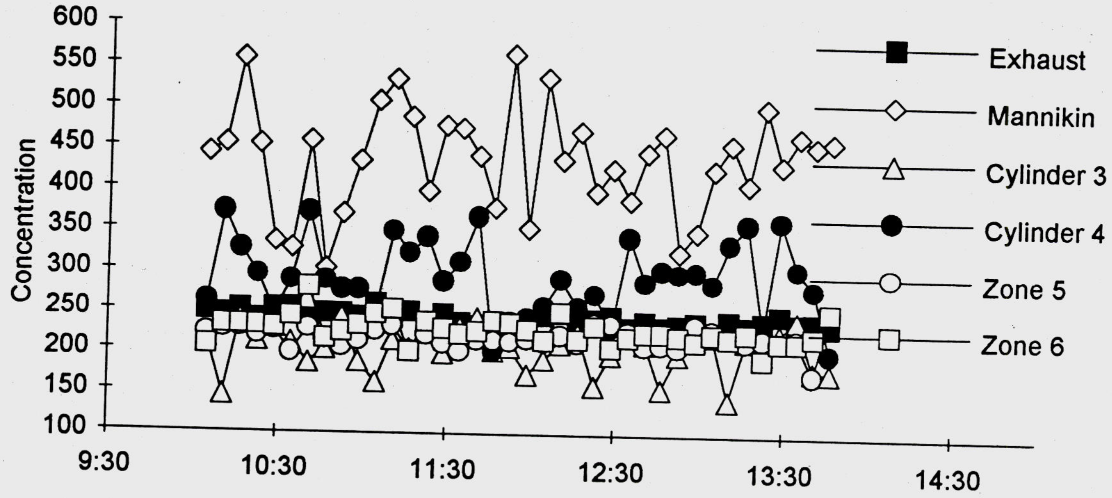


Poor remocal effectiveness (less than 1), except for the manikin and close to the ground.

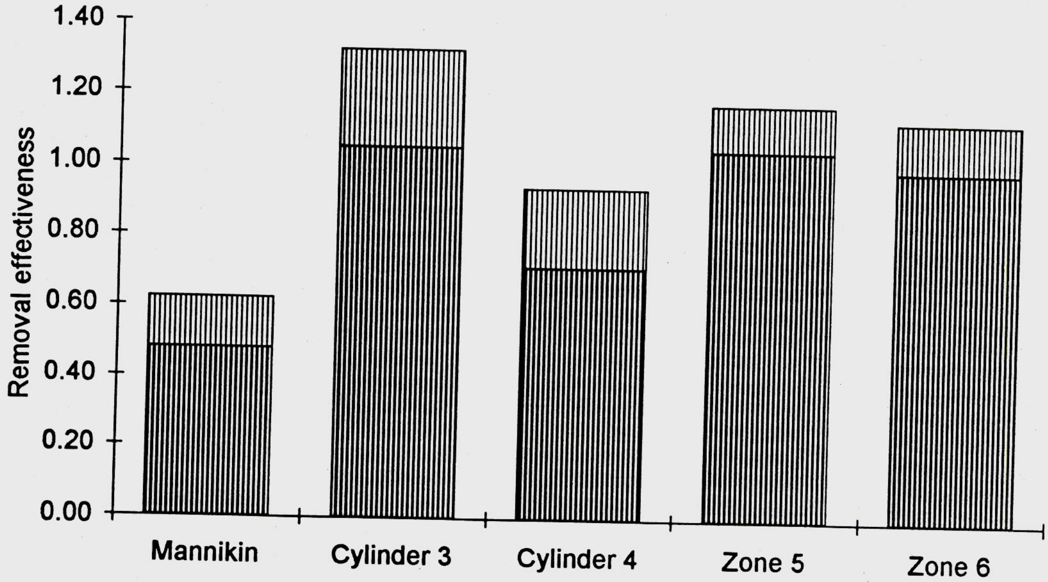
File EK203-3 **Piston ventilation with closed cooling ceiling** **VIII**

Sampling Tube Length 16.00 m
Air Pressure 101.33 kPa
Normalization Temperature 22.0 C
Start Time 1992-03-04 10:05
Stop Time 1992-03-04 14:09
Number of Samples 228

Internal load 3155 W
60.0 W/m²
Air flow rate 788 m3/h
5 /h
Probability for confidence 0.95



N2 O mg/m3	1 Exhaust	2 Mannikin	3 Cylinder 3	4 Cylinder 4	5 Zone 5	6 Zone 6
Average	242	438	204	293	218	228
Conf. Interval	6	55	23	39	11	14
Removal Effectiveness		0.55	1.19	0.83	1.11	1.06
Confidence Interval		0.07	0.14	0.11	0.06	0.07



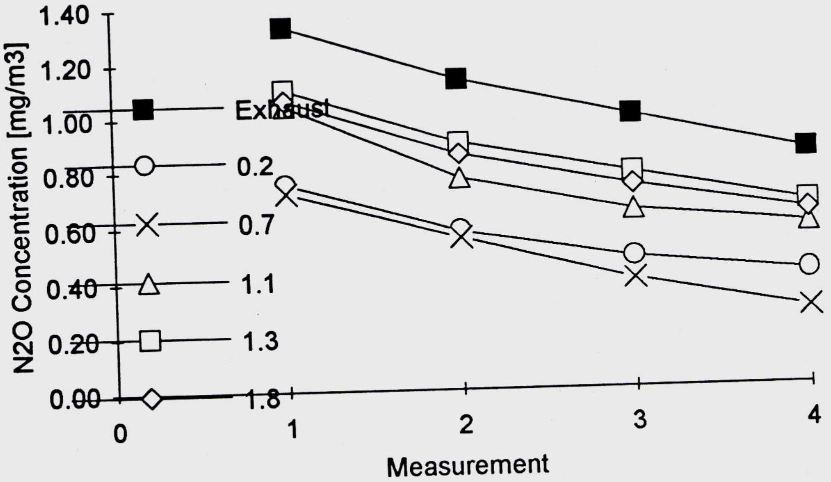
Poor removal effectiveness for the manikin: she gets all the contaminants generated by cylinder 4!

File EK 303-3 **Piston ventilation with closed cooling ceiling**

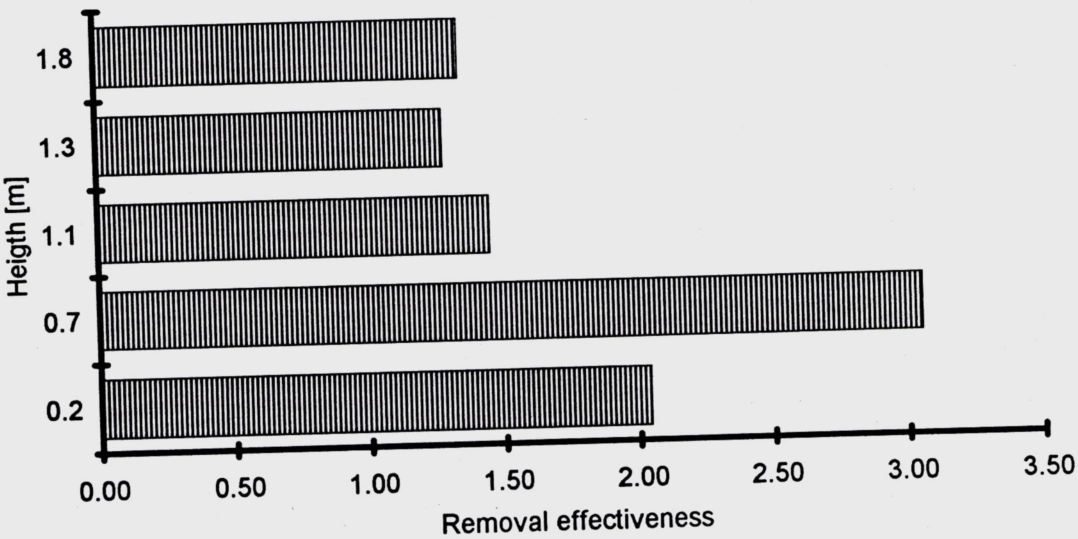
Start Time : 1992-03-04 14:22
Stop Time : 1992-03-04 14:48
Number of Recorded Samples : 25

	Exhaust	0.2	0.7	1.1	1.3	1.8
Average	1.08	0.55	0.49	0.76	0.86	0.82
Conf. Interval	0.21	0.15	0.20	0.21	0.19	0.19
Removal Effectiveness		1.94	2.22	1.42	1.25	1.31
Confidence interval		0.65	1.00	0.48	0.37	0.40

Note that N2O concentrations in file EK 303-3 decay with time. This should not be the case if N2O were injected at constant flow rate. Interpretation for the last concentration measurement follows, but results are dubious.



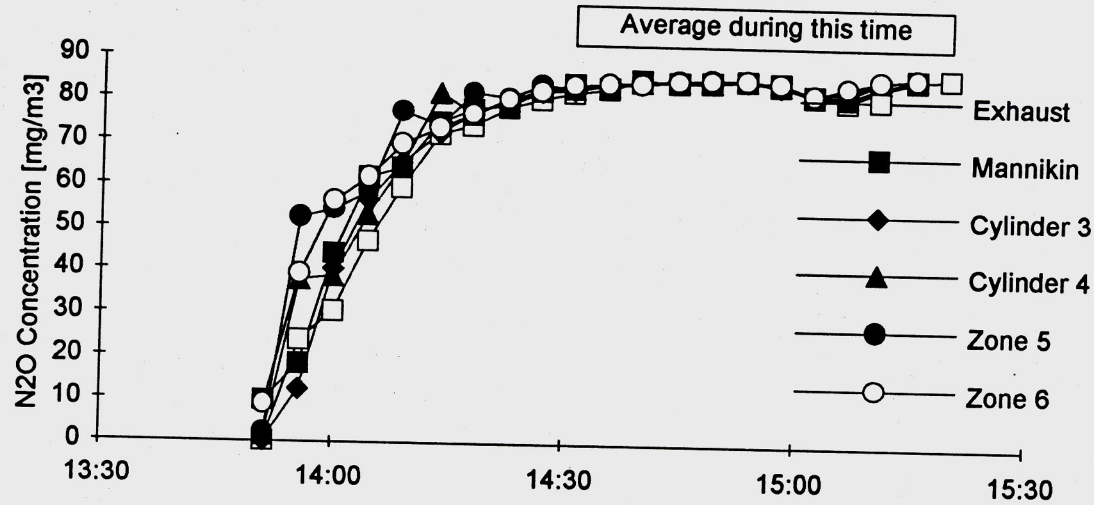
Position	Exhaust	0.2	0.7	1.1	1.3	1.8
N2O mg/m3	0.85	0.42	0.28	0.59	0.66	0.63
Removal effectiveness		2.04	3.05	1.45	1.29	1.35



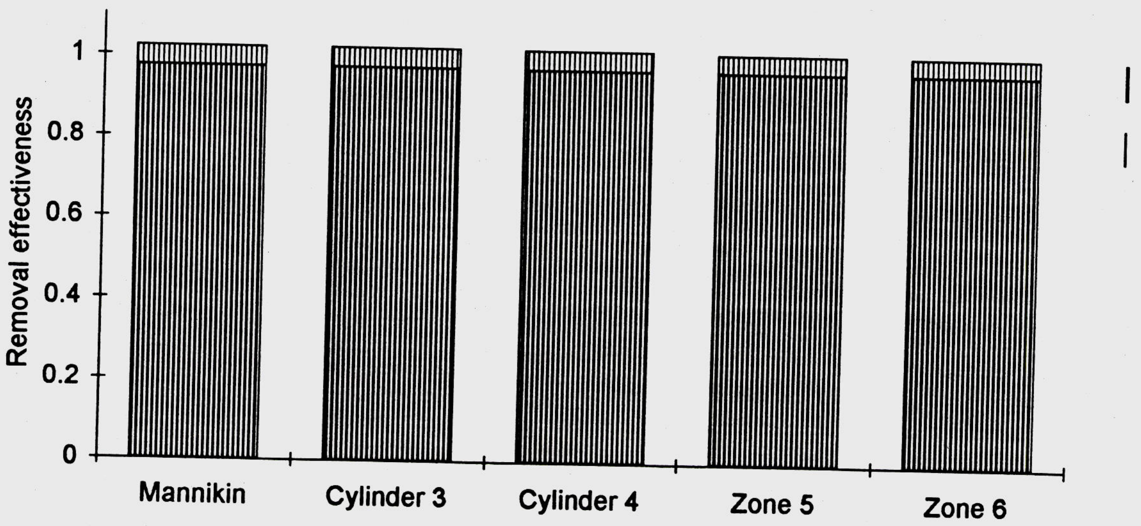
EK424-4 | **Piston ventilation with structured cooling ceiling** | **IX**

Sampling Tube Length	16.00 m
Air Pressure	101.33 kPa
Normalization Temperature	22.0 C
Start Time	1992-04-27 13:50
Stop Time	1992-04-27 15:20
Number of Samples:	102

Probability for confidence 0.95



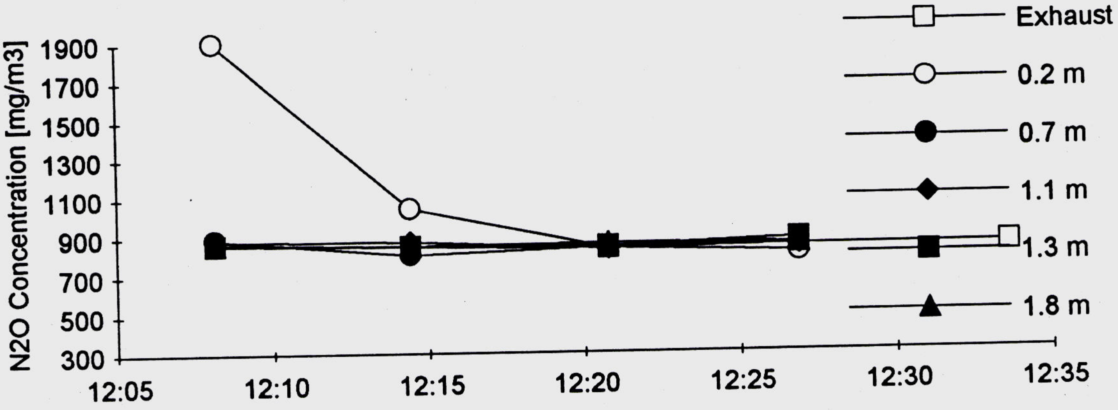
	Exhaust	Mannikin	Cylinder 3	Cylinder 4	Zone 5	Zone 6
Average	84	85	85	85	85	85
Conf. Int.	2	1	1	1	1	1
Removal Effectiveness		1.00	1.00	1.00	0.99	0.99
Confidence Interval		0.02	0.02	0.02	0.02	0.02



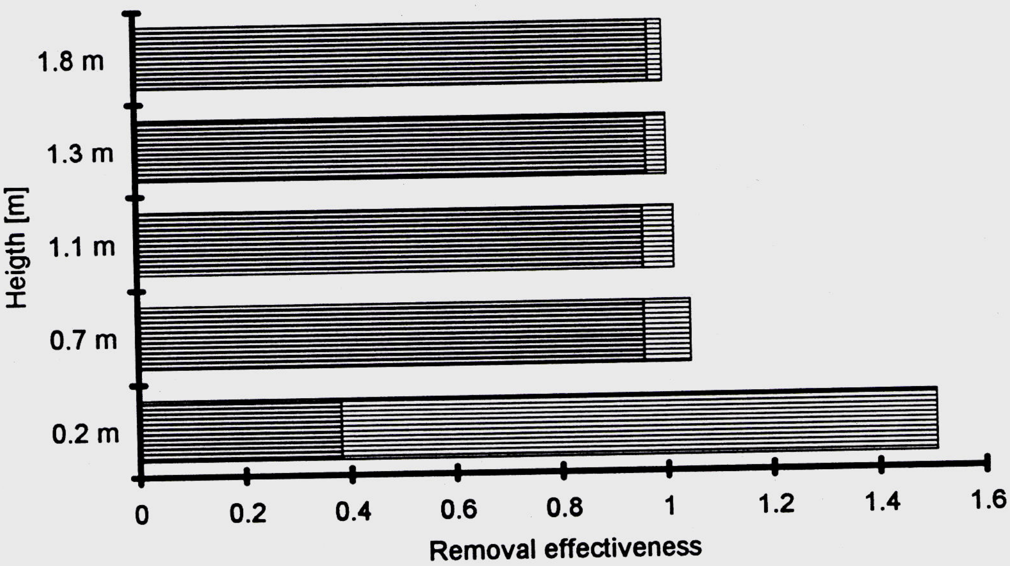
The concentration was averaged on measurements taken during the last hour, when steady state is achieved.

File EK 324-3 **Piston ventilation with structured cooling ceiling** **IX**

Start Time	1992-04-24 12:07
Stop Time	1992-04-24 12:34
Number of Samples	25



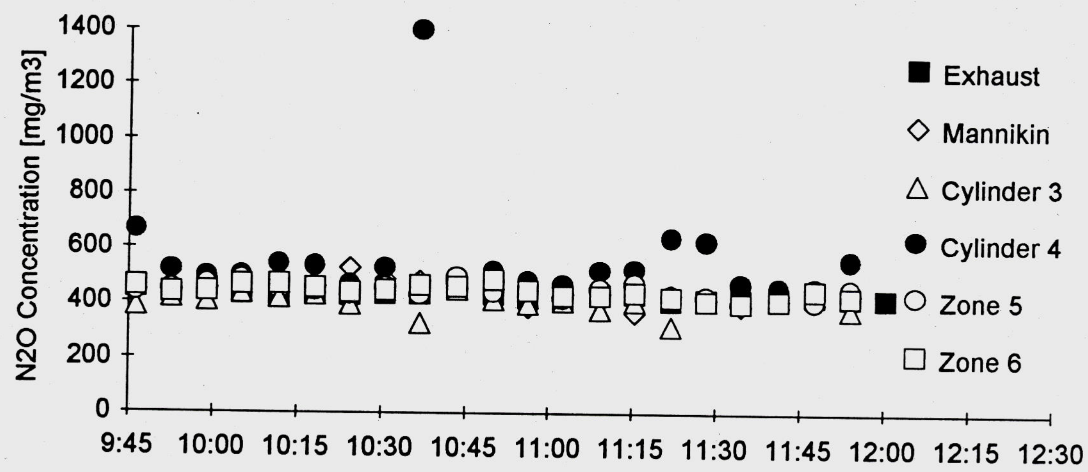
hh:mm	Exhaust	0.2 m	0.7 m	1.1 m	1.3 m	1.8 m
Average	844	893	842	855	856	856
Conf. Int.	10	533	36	24	14	7
Removal Effectiveness		0.94	1.00	0.99	0.99	0.99
Confidence Interval		0.56	0.04	0.03	0.02	0.01



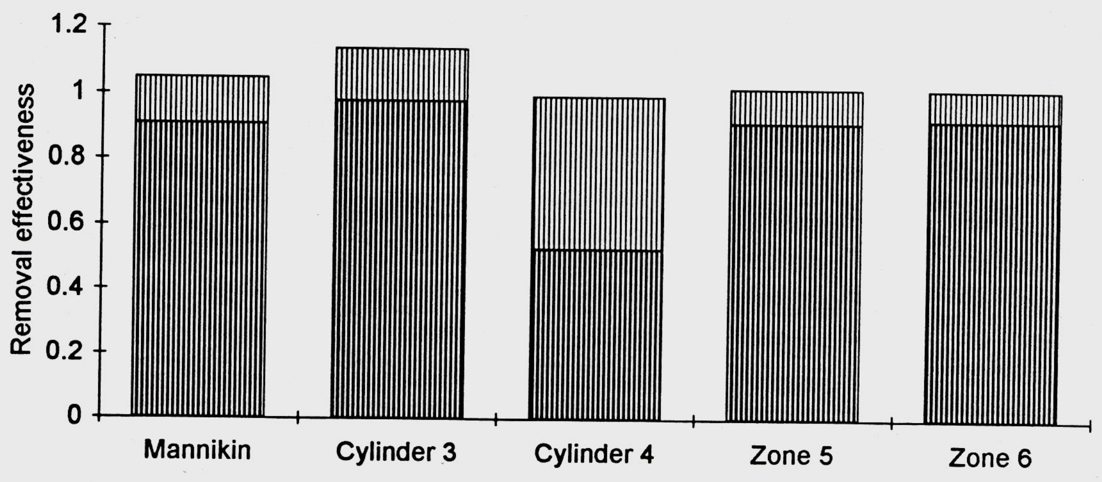
Strong mixing is achieved within the room. No location shows a removal efficiency significantly different from 1..

EK223-4 **Piston ventilation with structured cooling ceiling** **X**

Sampling Tube Length	16 m		
Air Pressure	101.33 kPa	Internal load	3158 W
Normalization Temperature	22 °C		60.1 W/m²
Start Time	1992-04-23 09:45	Air flow rate	526 m3/h
Stop Time	1992-04-23 12:01		3.3 /h
Number of Samples	127	Probability for confidence	0.95

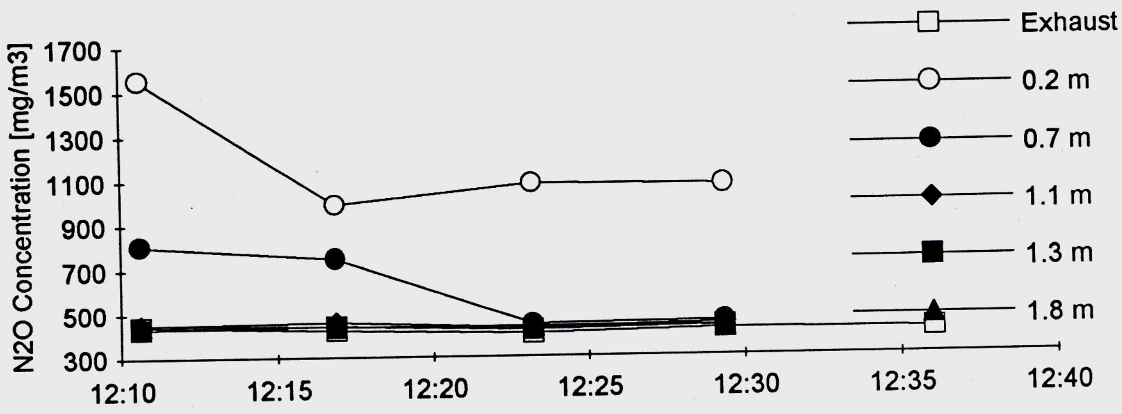


	Exhaust	Mannikin	Cylinder 3	Cylinder 4	Zone 5	Zone 6
Average	428	438	404	563	443	441
Conf. Int.	11	30	29	172	22	18
Removal Effectiveness		0.98	1.06	0.76	0.97	0.97
Confidence Interval		0.07	0.08	0.23	0.05	0.05

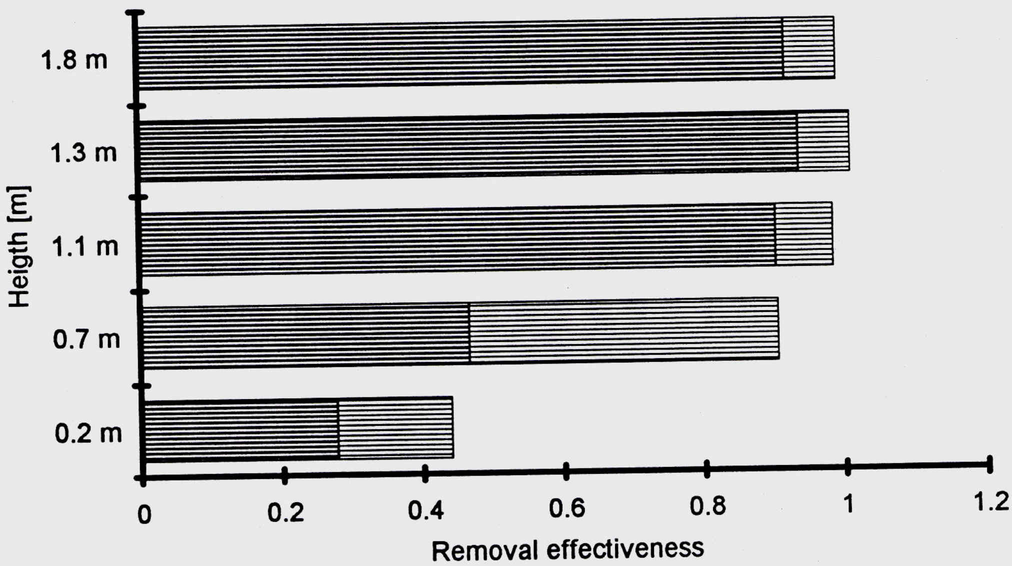


File EK 323-3 **Piston ventilation with structured cooling ceiling** **X**

Start Time	1992-04-23 12:10
Stop Time	1992-04-23 12:36
Number of Samples	25



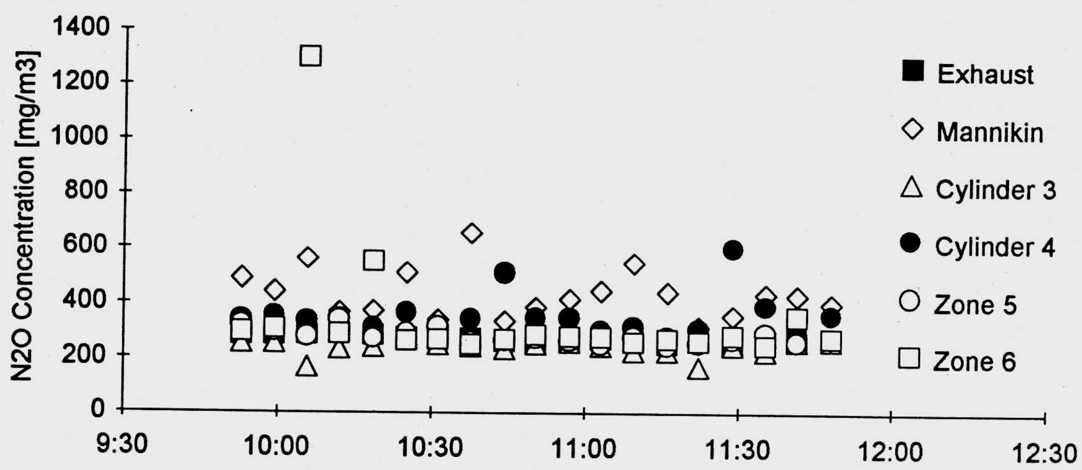
	Exhaust	0.2 m	0.7 m	1.1 m	1.3 m	1.8 m
Average	421	1172	614	446	433	441
Conf. Int.	14	265	195	12	8	9
Removal Effectiveness		0.36	0.69	0.94	0.97	0.95
Confidence Interval		0.08	0.22	0.04	0.04	0.04



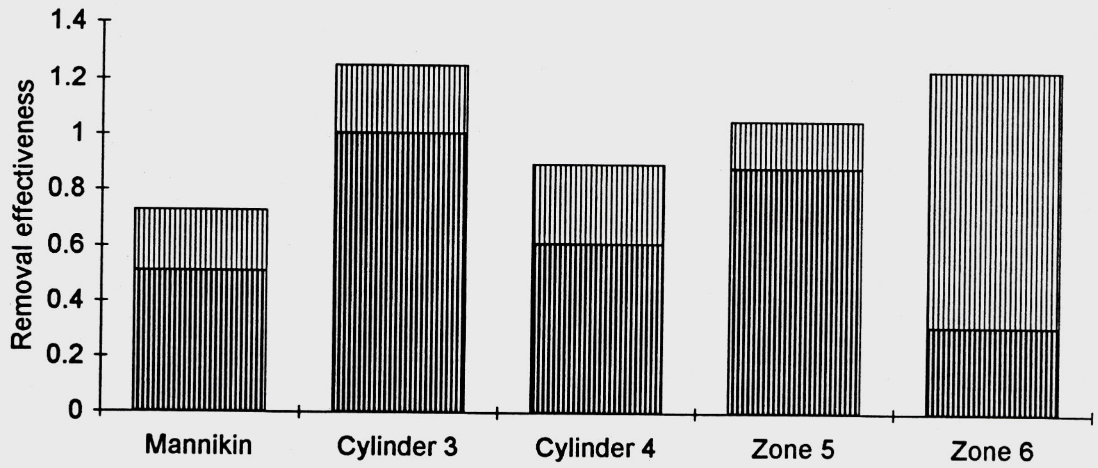
Some mixing is achieved within the room. However, poor removal efficiency at lowest levels.

EK227-4 **Piston ventilation with structured cooling ceiling** **XI**

Sampling Tube Length	16m		
Air Pressure	101.33 kPa	Internal load	3158 W
Normalization Temperature	22.0 C		60.1 W/m²
Start Time	1992-04-27 09:52	Air flow rate	526 m3/h
Stop Time	1992-04-27 11:53		3.3 /h
Number of Samples:	114	Probability for confidence	0.95

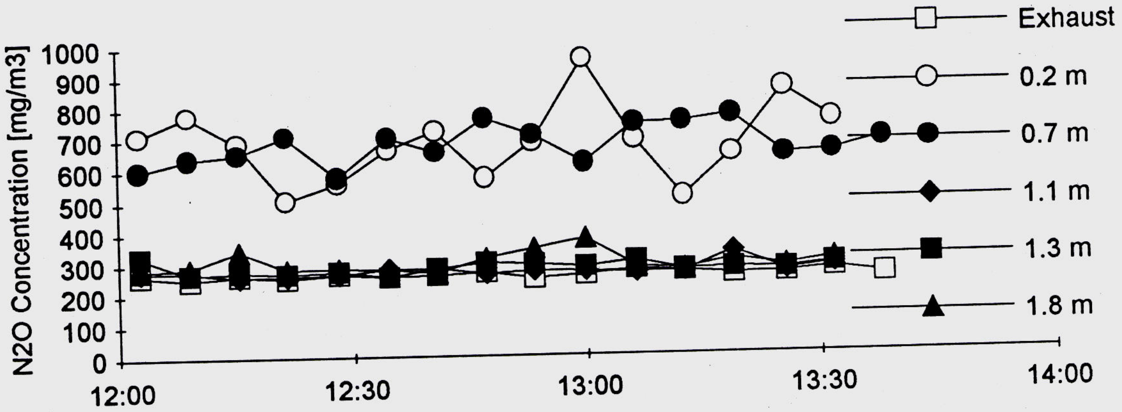


	Exhaust	Mannikin	Cylinder 3	Cylinder 4	Zone 5	Zone 6
Average	270	435	239	357	278	347
Conf. Int.	10	75	24	65	22	206
Removal Effectiveness		0.62	1.13	0.76	0.97	0.78
Confidence Interval		0.11	0.12	0.14	0.08	0.46

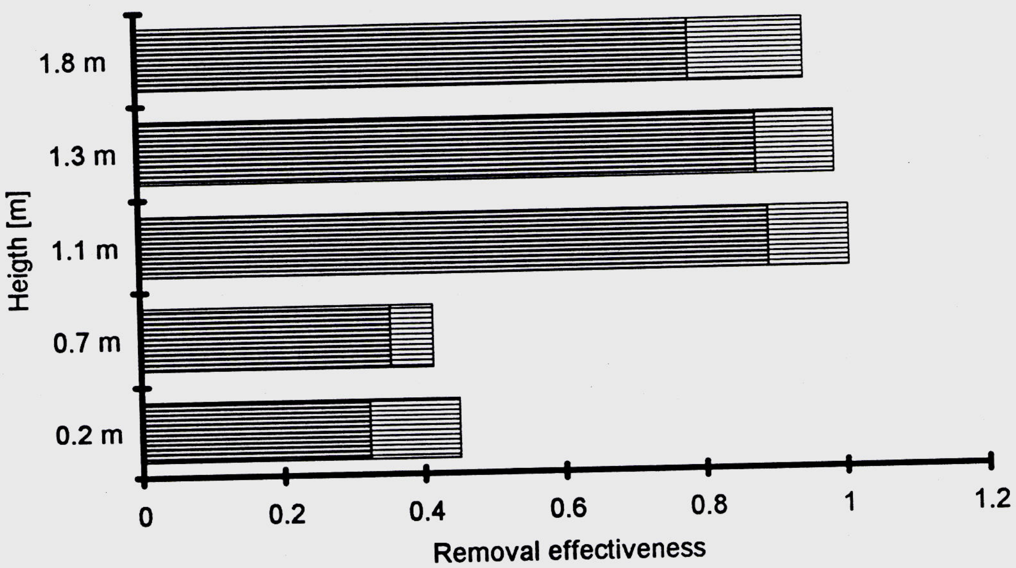


File EK 324-3 **Piston ventilation with structured cooling ceiling** **XI**

Start Time	1992-04-27 12:02
Stop Time	1992-04-27 13:40
Number of Samples	93



hh:mm	Exhaust	0.2 m	0.7 m	1.1 m	1.3 m	1.8 m
Average	260	672	676	273	278	300
Conf. Int.	7	110	51	15	15	27
Removal Effectiveness		0.39	0.38	0.95	0.93	0.87
Confidence Interval		0.06	0.03	0.06	0.06	0.08



Poor removal efficiency (< 1) at every measured location.