OPTIMUM VENTILATION AND AIR FLOW
CONTROL IN BUILDINGS

17th AIVC Conference, Gothenburg, Sweden,
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# EFFICIENCY CHARACTERISATION OF VARIOUS VENTILATION CONFIGURATIONS

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Synopsis

The study concerns the ventilation of a parallelepiped shape room by means of several systems whose supplying and extracting methods differ, so the different thermic conditions applied to limits. To qualify the efficiency of each of these systems in relation with the various current criteria, we carried out measurements by means of a tracer gas, both with a transitory and a permanent flow.

At the same time, numerical simulations were carried out by means of a CFD code which solves the equations of the fluids mechanic, material and heat transfers associated with flows. These calculations results, after measurements validation, enable to accurately know the air movements in the ventilated room as well as the tracer gas concentrations distribution in the tested configurations.

From these calculation results, was also demonstrated how the complex behaviour of each of these ventilation systems can be characterised owing to the possibility of identifying it to a simple model, using a reduced number of parameters. These typical parameters can in turn be used to implement the system performance evaluation criteria.

These criteria allow to compare the various studied ventilation systems and class them in performance order. It can be seen that this classification can be modified depending on the selected criterion as well as the chosen ventilated area.

The study results equally show the interest of the use of numerical simulation together with experiments, thus extending the range of results in order to generalise conclusions.

## 1. Introduction

In this paper, a methodology is described to determine the performances of different ventilation systems in a room with a local emission of pollutant. This methodology is based on numerical calculation of air flows and transfers. First of all, this simulation has been applied to a room where measurements were done, in order to validate the calculation.

Then the methodology was applied to four elementary ventilation systems in a room, in order to qualify their efficiency using performance criteria which are defined in this study.

It was shown that the methodology can be used to study and to qualify the efficiency of a defined ventilation strategy in a room.

The comparisons between the different studied configurations show that the performance classification strongly depend on the criteria and on the observation point into the room.

## 2. Measurements

The measurements used for comparisons with calculations were done in a parallelepipedic room represented in Figure 1.

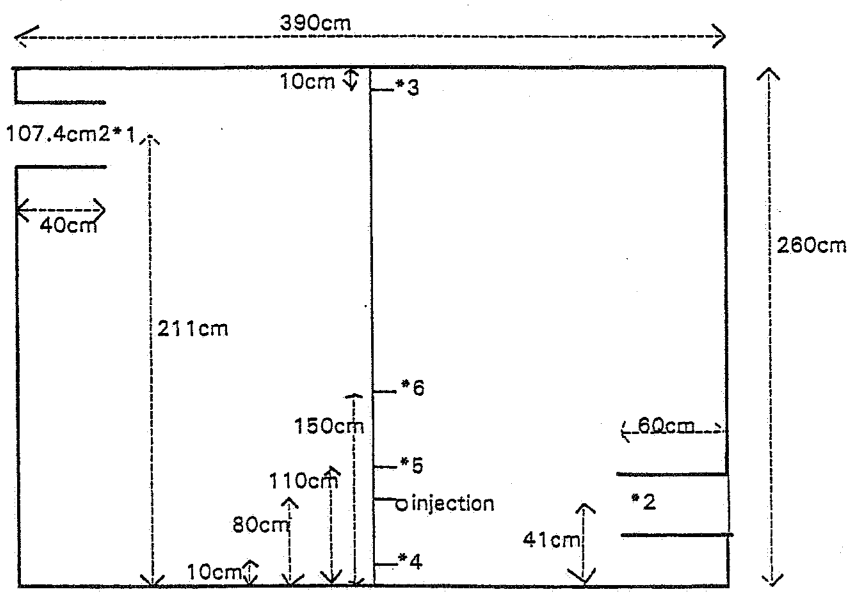



Figure 1 : Test room with concentrations measurement points

In the considered ventilation system, air is supplied on the top of one wall (middle of the wall) and extracted at the bottom of the opposite wall (middle of the wall).

The pollutant is $N_2O$ ; it is generated with constant flow, in the center of the room, at a 0.8 m height.

This type of pollutant has been chosen because it is possible to measure low concentrations and because its density is the same that the $CO_2$ one, which represents one of the most common pollutant in occupied spaces.

The positions of the measurement points are shown on the same Figure 1 ; four points are on the vertical, at center and different heights ; one control point is in the air inlet, another is in the air outlet.

The experiment is divided in two periods : after establishing the ventilation scheme, the pollutant is generated, continuously, until constant concentrations are reached ; then the pollutant generation is stopped, and the ventilation goes on, until the initial zero concentration is get.

Measurements give the concentrations evolution during the different periods : continuous generation period, transitory increasing and decreasing periods.

## 3. Numerical simulation

The simulation consists in integrating Navier-Stokes equations in the studied field. The method of the finite volumes is used, with a three-dimensional representation of the space.

The FLUENT CFD is used. The turbulence is taken into account with a two equations model (k-e).

The pollutant diffusion in the air is also represented (molecular and turbulent diffusion) ; the buoyancy effect is also represented, and it induces different forces on the local concentration of pollutant which is denser than the air. The calculation were done in isothermal conditions, with adiabatic walls ; the pollutant is generated at the same temperature as the indoor air.

As in the experiments, the calculations were done for different specific periods : stationary period with continuous generation of pollutant, and transitory period representing the evacuation of N2O after a pollution period.

The Figures 2 and 3 show the comparisons between measurements and calculations for both periods.
Figure 2 shows the vertical profile of $N_2O$ concentration at the center of the room.

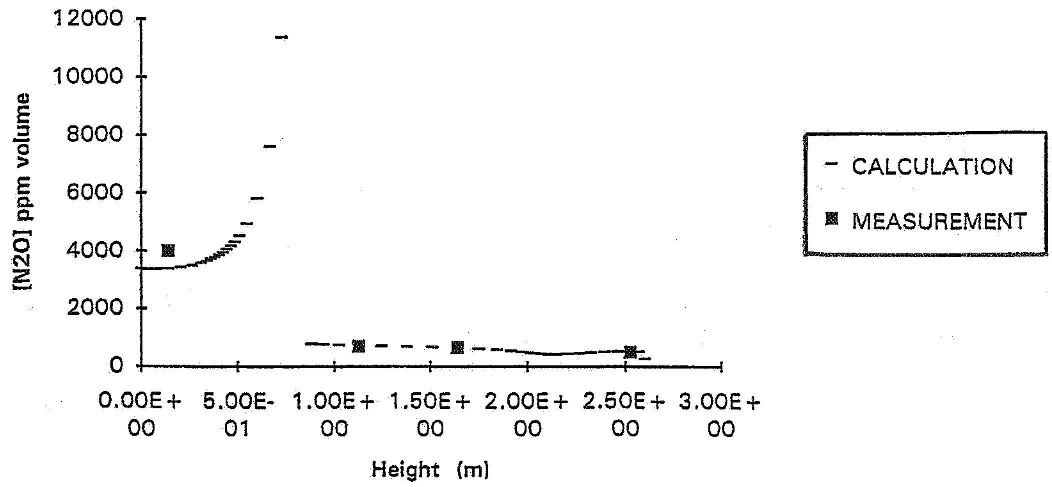
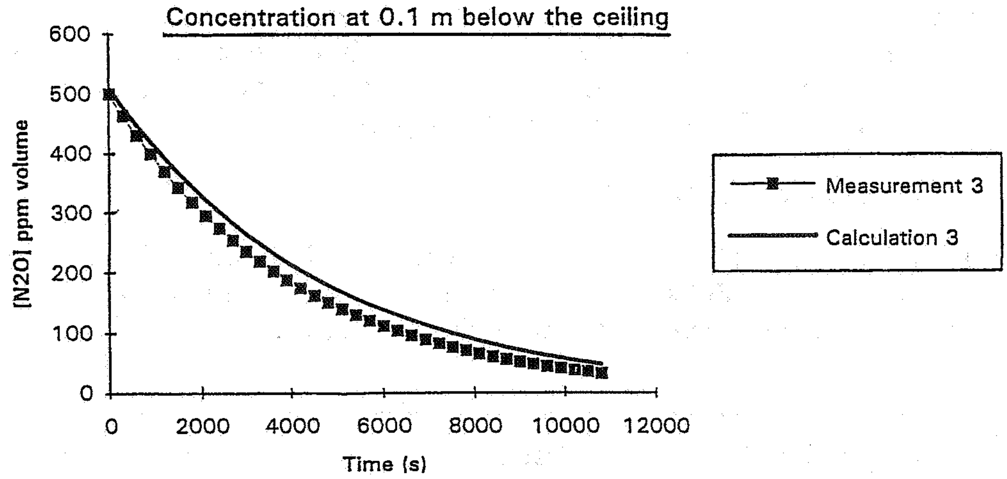
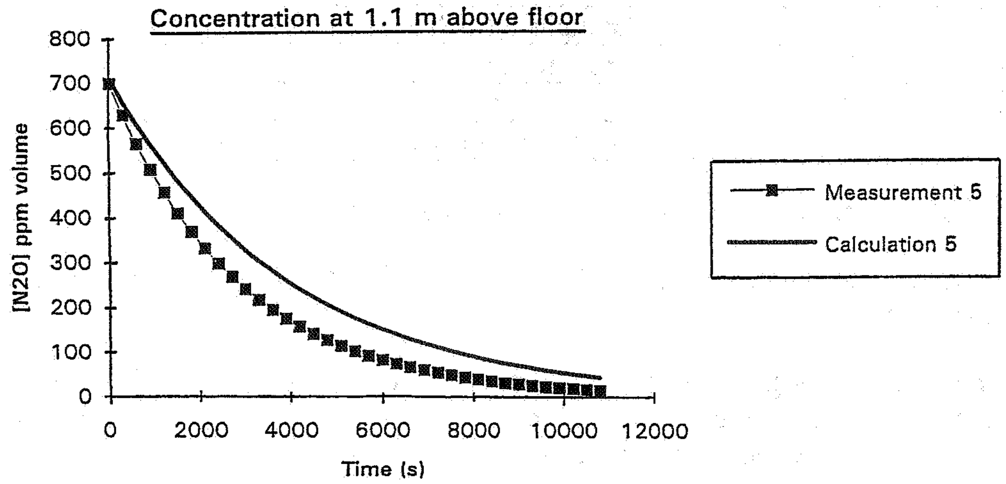



Figure 2 : Profile of concentration in the middle of the room

Figure 3 shows the decrease of the N2O concentration at different measurement points, during the time, after the end of the generation period.



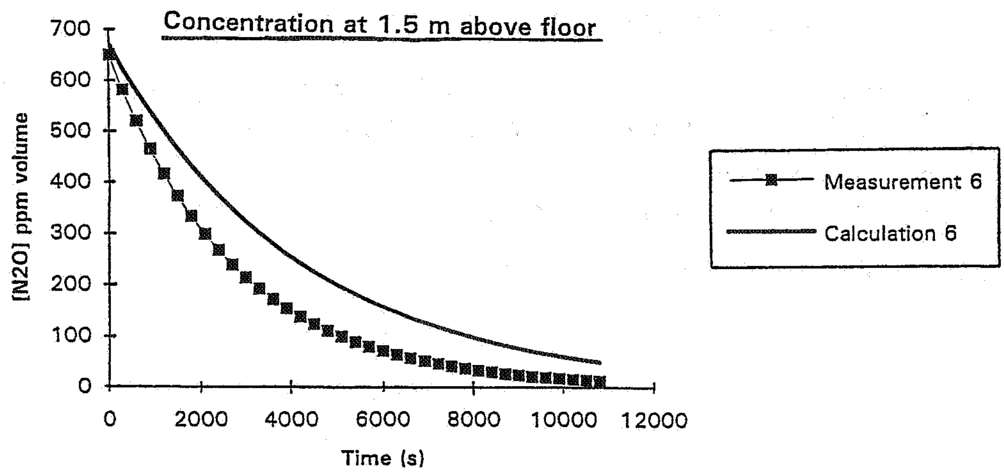




Figure 3 : Evolutions of concentrations at different points comparison between measurements and calculation

Measurements and calculations are congruent ; so, the simulation can be used for a practical study.

## 4. Exploitation of numerical results

In this part of the study, different configurations are compared, according to their efficiencies, which are established using the criteria coming from the simulation results : results in steady state conditions with continuous pollutant generation, and results in dynamic conditions when the concentration decreases after a pollution phase.

### 4.1. The studied configurations

On the geometrical base defined in paragraph 2 (Figure 1), four configurations were considered. They differ in the relative positions of supply and exhaust devices. The configurations are described in Table 1.There are all mixing ventilation.

Table 1

| Configuration n° | Name | Supply | Exhaust |
|---|---|---|---|
| 1 | "straight up-up" | up | up |
| 2 | "cross up-down" | up | down |
| 3 | "cross down-up" | down | up |
| 4 | "straight down-down" | down | down |

In all the cases, the air change rate is two volumes per hour (so an air flow of 108 $Nm^3/h$).

The pollutant used here is the CO2 ; it is introduced in the same way as with the measurements.

The calculation gives, among the results, the pollutant concentrations in two particular points situated in the middle of the room at 0.1 m and at 1.1 m above the floor. These results, in the steady state and dynamic conditions are used to qualify each of the ventilation systems.

### 4.2. Ventilation efficiency in steady state conditions

It is characterised with a criterion called "pollutant removal effectiveness" [2, 4, 5], which represents the capability of the system to evacuate a continuous production of pollutant. In the simple case where the supply air is free of pollutant, it is defined by the ratio between the pollutant concentration at the exhaust $\overline{[CO_2]}$ and the pollutant concentration at the considered point $[CO_2]_\infty$ in the ventilated room :

$$\eta_e = \frac{\overline{[CO_2]}}{[CO_2]_\infty}$$

where $\overline{[CO_2]}$ is the concentration in steady state conditions at the exhaust, which is simply calculated with the ratio between the pollutant generation flow on the ventilation air flow.

The better the local ventilation effect is, the bigger the pollutant removal effectiveness is.

### 4.3. Ventilation efficiency in dynamic conditions

As the figure 4 gives an example, the results show that during the period following the pollution phase, the decrease of the concentration in one point is always very close to a linear system response :

$$[CO_2]=[CO_2]_\infty \bullet \left[1-EXP\left(\frac{-t}{T}\right)\right]$$

where t represents the time. This fact allows to characterise the dynamic behaviour of the ventilation system at a constant time.

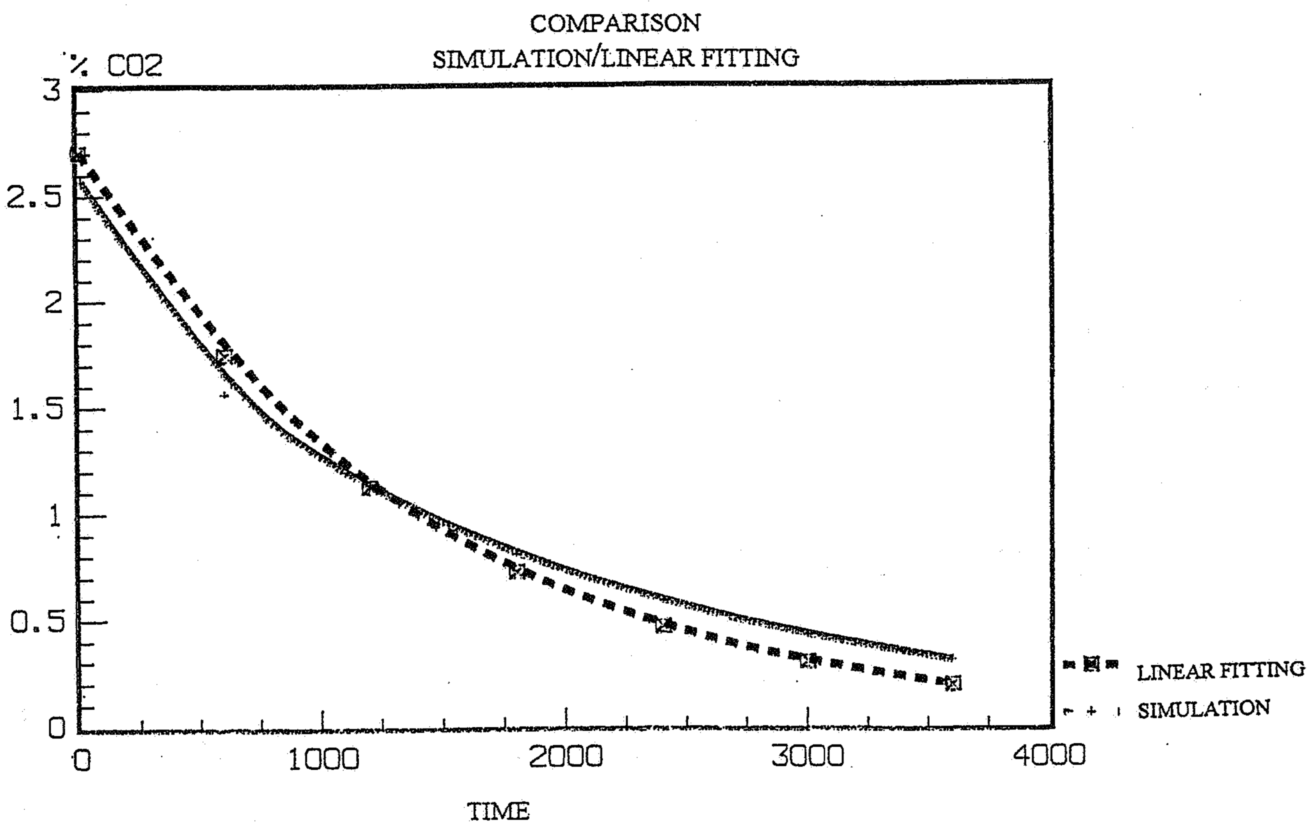



Figure 4 : Decrease of concentration in one point, during the time - Approximation with simple model

Then, this constant time can be used to determine the "air change efficiency". This criterion characterises the efficiency of the ventilation system in quickly replacing the polluted indoor air [3] with new (or fresh) air. This criterion is expressed by the ratio between the average duration for changing air and the previously defined constant time :

$$\rho_r=\frac{\bar{\tau}}{T}$$

The quicker the ventilation is able to evacuate a temporary pollution from indoor air, the bigger the air change efficiency is.

4.4. Application to the studied configurations

The previous defined criteria are calculated for the four studied configurations, and for the two observation points. The results are summed up in Table 2.

Table 2

| Configuration | Position (observation point) | Pollutant removal effectiveness | Air change efficiency |
|---|---|---|---|
| 1 | 1 | 0.704 | 1.044 |
| | 2 | 0.799 | 0.847 |
| 2 | 1 | 0.897 | 1.318 |
| | 2 | 1.070 | 1.082 |
| 3 | 1 | 1.241 | 1.115 |
| | 2 | 1.006 | 0.915 |
| 4 | 1 | 1.192 | 1.009 |
| | 2 | 0.957 | 0.834 |

These values allow to classify the four studied ventilation systems, according to their efficiencies.

If we consider the observation point n°2, the more closest to the occupied zone, then we get the following decreasing classification related to both criteria (Table 3).

Table 3

| Classification | Pollutant removal effectiveness | Air change efficiency |
|---|---|---|
| 1 | "cross up-down" | "cross up-down" |
| 2 | "cross down up" | "cross down up" |
| 3 | "straight down-down" | "straight up up" |
| 4 | "straight up up" | "straight down-down" |

Then, if we are interested by the pollution at the floor level, we can choose the observation point n°1. The classification is then given in Table 4.

Table 4

| Classification | Pollutant removal effectiveness | Air change efficiency |
|---|---|---|
| 1 | "cross down-up" | "cross up-down" |
| 2 | "straight down-down" | "cross down up" |
| 3 | "cross up-down" | "straight down-down" |
| 4 | "straight up-up" | "straight up-up" |

As the ventilation system in configuration "cross up-down" seems to be the more efficient in the majority of the cases (all configurations are mixing ventilation), the results show that the relative interest of one system compared to another differs according to the criteria and to the position into the room.

## 5. Conclusion

This work, made on four ventilation systems, showed the interest in using the numerical simulation which allows to study in an accurate and detailed manner, complex and dynamic phenomena.

We also showed how the detailed results in the concentrations evolution in time given by the calculation, can be reduced, by a simple model identification, to some specific parameters. These parameters can be used, at the end, to apply the evaluation criteria of the systems performances.

These criteria allow to compare the different ventilation systems, but we can see that the performance classification depends on the chosen criterium, and on the region of the space in the considered ventilation room.

Today, comparisons and calculations are made with non-isothermal conditions.

## Acknowledgements

The ADEME (Agence de l'Environnement et de la Maîtrise de l'Energie), the French Agency for the Environment and the Energy Saving, is taking part in this study.

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