VENTILATION EFFICIENCY UNDER VARIOUS HEATING AND AIR-EXHAUSTING CONDITIONS: AN EXPERIMENTAL STUDY

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ABSTRACT

This work, along with the experimental measurements on which it is based, was carried out in the framework of research undertaken by the French “Groupe de Pilotage sur la Qualité des Ambiances” (GPQA), whose task was to initiate and co-ordinate work on air quality on a national scale.
The aim of this work is to investigate experimentally the influence of different sources of disturbance (heating systems and a manikin) on the ventilation efficiency. Ventilation efficiency is an index which expresses a ventilation system’s capacity to evacuate pollutants. The tracer gas technique was used to determine this index. After introducing the MiniBat experimental cell, the results of our experiments integrating different sources of disturbance (a convector, a radiant panel, a ventilo-convector and a manikin) are presented. The influences of these sources of disturbance on ventilation efficiency are studied and compared to results in isothermal conditions.
The main conclusion is that the effect of disturbance is to mix the air, thus ventilation efficiency, even at low flow rates. So, in fact the disturbance is not necessarily “disturbing”.

KEYWORDS

Ventilation efficiency, experimental cell, heating systems, tracer gas

INTRODUCTION

Socio-technical change has resulted in many people, in the Western world, spending the greater part of their lives (often more than 90%) in an artificial climate: offices, dwellings, cars, etc. More and more attention must therefore be paid to the quality of our indoor environment, and in this context, ventilation and thermal comfort are fundamental considerations. This work, along with the experimental measurements on which it is based, was carried out in the framework of research undertaken by the French “Groupe de Pilotage sur la Qualité des Ambiances” (GPQA), whose task is to initiate and co-ordinate work on air quality on a national scale. The idea is that within this framework, the main types of ventilation system will be studied experimentally, along with different sources of disturbance, i.e., a heating system and a manikin. This study is the continuation of previous experimental work carried out in our laboratory (CASTANET, 1998), but without sources of disturbance. The aim here was to determine the effectiveness of ventilation systems in removing pollutants from an enclosed space, and their effects on thermal comfort. The conditions of the experimentations are placed in average winter conditions in regard with the French climate.

To begin with, some general points about air quality and thermal comfort are given, then a description of the experimental apparatus and the results obtained are presented. Finally, there is a discussion on the effects of disturbance on ventilation efficiency in the chosen experimental conditions.

VENTILATION EFFICIENCY

In order to compare the different systems of ventilation, it is necessary to lay down a certain number of general criteria and concepts (such as that of "ventilation efficiency"), and also a set of indices for characterising ventilation. These indices take account of the air entering a space and the air already present there, as well as the distribution of pollutants. In this study, two indices are used: average ventilation efficiency, ε_C in the overall experimental cell, and average ventilation efficiency in the occupancy zone, ε_{Coz}.

The particularities of an occupancy zone depend on the geometry of the space in question, and its utilisation. The following configuration was adopted in the present study:

- two horizontal planes, situated 0.10 and 1.80 m above the floor;
- vertical planes at a distance of 0.50 m from the outside and inside walls.

If we suppose that the supply air is free of pollutants these indices can be written (SANDBERG, 1981), (AWBI and al., 1993):

$$\varepsilon_C = \frac{C_e}{\overline{C}} \text{ and } \varepsilon_{Coz} = \frac{C_e}{\overline{C_{OZ}}}$$

C_e being the exhaust tracer gas concentration, $\overline{C}$ and $\overline{Coz}$ mean tracer gas concentrations respectively in the cell and in the occupancy zone.

THE EXPERIMENTAL APPARATUS

The experiments were carried out in the MiniBat experimental cell at CETHIL (LAPORTHE, 2000). This installation comprises two cells of the same dimensions: 3.10 m × 3.10 m × 2.50 m high. Cell 1 is separated by a glass wall from the climatic chamber, whose air-treatment system can produce temperatures of between -10 and +30°C. For the experiments presented in this paper, this temperature was maintained at about 10°C with an heating system in the cell and at around 20°C in isothermal conditions. The thermal guard was kept at 20°C, representing adjacent spaces.

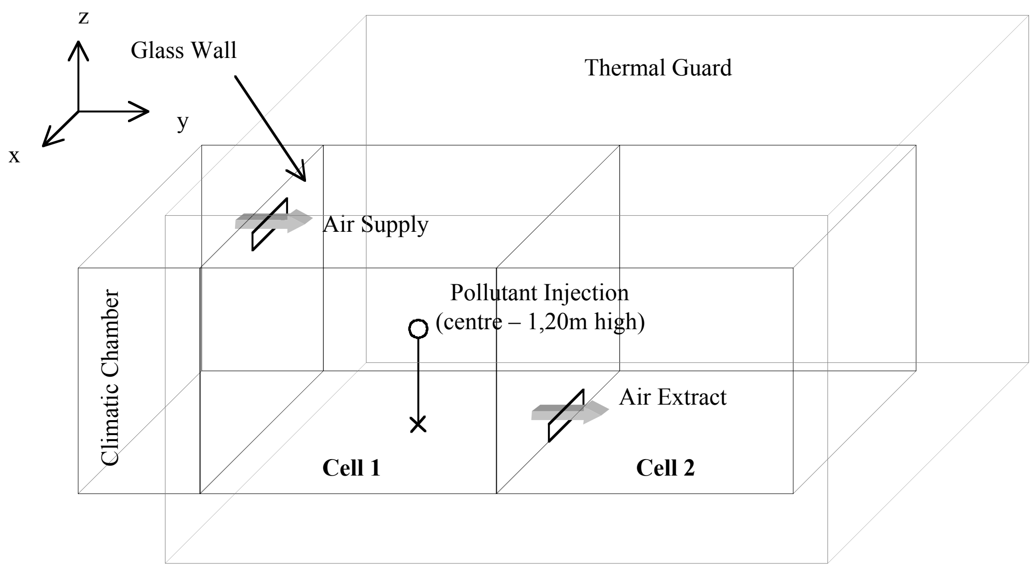

Figure 1: The experimental cell MINIBAT

The study was carried out exclusively in MiniBat cell 1, whose ventilation system consisted of a fixed inlet (situated at the centre of the cell and close to the ceiling, near the glass wall), a mobile extraction outlet, and a network of pipes for blowing air into, and extracting it from, the cell. The exhaust flow could be set at arbitrary values. For the experiments in question, the outlet flow was set at 1 ach/h, otherwise 24 m^3/h. The supply air came directly from the climatic chamber. The dimensions of the inlet and the outlet were:

- inlet: 0.25 m wide, 0.02 m high ;
- outlet: 0.20 m wide, 0.10 m high.

Two positions of the air exhaust, *a* and *b*, were pre-set.

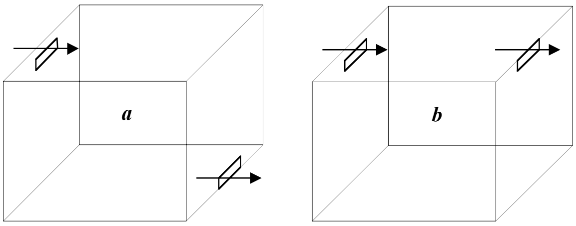

Figure 2: Test position of exhaust

The MiniBat cells are equipped with a number or sensors for measuring surface and air temperatures, as well as air velocities and gas concentrations. They are also equipped with a device which can be used to move the sensors over different vertical planes. This device consists of three motors which actuate a metal arm on which is mounted an array of six sensors: two type-K thermocouples for air temperatures, two omnidirectional hot-wire probes for air speeds, and two measuring points for gas concentrations. The measurement and collection procedures are carried out by a computer-controlled and a data-acquisition unit. The sensor array moves over a mesh grid whose spacing is defined by the user. For the tests presented here we have 396 measuring points for the median plane with an irregular mesh-grid and 168 measuring points for the lateral one, with a regular 20 cm $\times$ 20 cm mesh-grid.

The tracer-gas method is the most widely used for studying the movement and quality of air in an enclosed space. They are also the only ones that can be used experimentally to characterise:

- ventilation systems (e.g. with regard to air flows and movements),
- air quality in terms of age and the migration of pollutants.

Sulfur hexafluoride (SF_6), used as the tracer gas, was injected continuously into the centre of cell at a height of 1.25 m, through a table-tennis ball in which a large number of small holes had been made. The injection flow rate was 15 ml/mn.

THE EXPERIMENTS

Air temperatures, air velocities and SF_6 concentrations were measured on two vertical planes:

- plane 1: X_1=1.55 m (median plane)
- plane 2: X_2=0.86 m (lateral plane)

The first three experiments (test 1 to 3) have been made in isothermal conditions: without heating system, and climatic chamber at the same temperature than in the cell. It's only the air flow that changes: 2 ach, 1 ach and 0.5 ach.

The three later one (test 4 to 6) correspond to three different heating systems placed near the glass wall, under the air inlet with a power set at 310 W: a convector, a radiant panel and a ventilo-convector (air velocity on position "low"). In these experiments, the air flow is of 1 ach. Test 7 corresponds to a convector heating with an air flow of 0.5 ach. The last one (test 8) is a configuration of a convector heating, 1 ach and presence of a manikin.

The manikin is a hollow metal cylinder 0.37 m in diameter and 1.20 m high, which simulates the presence of a sitting person. It is painted in black, and eight 25 W lamps are placed inside it. For the experiments presented here, the power emitted by the manikin, which was placed in the centre of the cell, was set at 90 W, which corresponds to the energy emitted by a sedentary human body.

Results

In TABLE 1, the values of ventilation effectiveness are given in isothermal cases and also with an heating system in the two measurement planes X_1 and X_2. The air flow rate Q_e has been taken from 0 to 2 ach/h. In non isothermal conditions, the temperature T_c of the climatic chamber, and so the air temperature inlet, was taken at near 10°C.

TABLE 1 : Results obtained

Test		Q_e m^3/h	T_c °C	ε_C		ε_{Coz}	
				X_1	X_2	X_1	X_2
1a	Isothermal, 2ach/h	47.7	20.7	0.93	1.02	0.90	1.02
2a	Isothermal, 1ach/h	23.8	20.5	0.94	0.96	0.94	0.94
3a	Isothermal, 0.5 ach/h	11.9	20.9	3.18	2.32	2.93	2.23
4a	Convector, 1ach/h	24.0	9.4	1.01	1.04	1.00	1.04
5a	Radiant panel, 1 ach/h	24.4	9.8	1.01	1.07	0.96	1.06
6a	Ventilo-convector, 1 ach/h	24.3	10.0	0.97	0.98	0.95	0.98
7a	Convector, 0.5 ach/h	11.6	10.0	1.00	1.02	1.00	1.01
8a	Convector and manikin, 1 ach/h	24.4	10.4	0.98	0.99	0.98	0.99
2b	Isothermal, 1 ach/h	23.9	20.8	0.74	0.63	0.68	0.61
4b	Convector, 1 ach/h	24.2	9.8	0.98	1.02	0.94	1.02
5b	Radiant panel, 1 ach/h	24.1	9.7	0.96	0.99	0.92	0.98
8b	Convector and manikin, 1 ach/h	24.8	10.0	1.04	1.06	1.05	1.06

Isothermal Tests

Concerning tests 1a and 2a (2 ach/h and 1 ach/h), the ventilation effectiveness is closed to 1. The differences observed between these two cases concern the concentrations values only: concentrations values for test 1a are inferior than values for test 2a. For test 3a (0,5 ach/h), ventilation effectiveness is largely superior to 1. But this doesn't mean a good extraction of the pollutant. Indeed, figure 3 shows a high pollutant accumulation near the ground. The concentrations values at this place are high (≈ 400 mg/m^3), when in the others parts of the cell, concentrations values are weaker (≈ 150 mg/m^3). That's why ventilation effectiveness is so high in this case: the mean tracer gas concentration is very inferior in the cell than at the extraction. Concerning tests 1a and 2a, concentrations values are nearly the same on the median plane and on the lateral plane. On the contrary, test 3a, with an air extract flow of 0.5 ach/h, the median plane, under the supply influence, records concentrations weaker than the lateral plane.

For the test 2b, the position of the exhaust cause a "short circuit", in the sense that the supply air in the room is extract directly, without ventilating the occupancy zone (ventilation effectiveness around 0.6). We observe also, that on the median plane the efficiency is better than on the lateral one: the air flow favours dilution in the plane of the inlet.

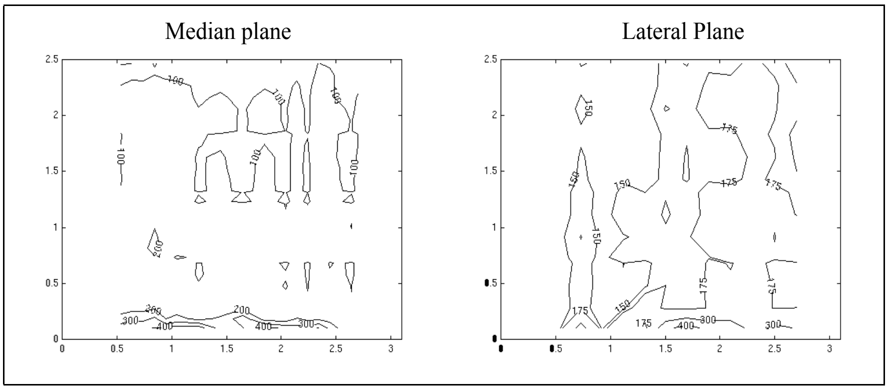

Figure 1 : Concentrations iso-curves – Test 3

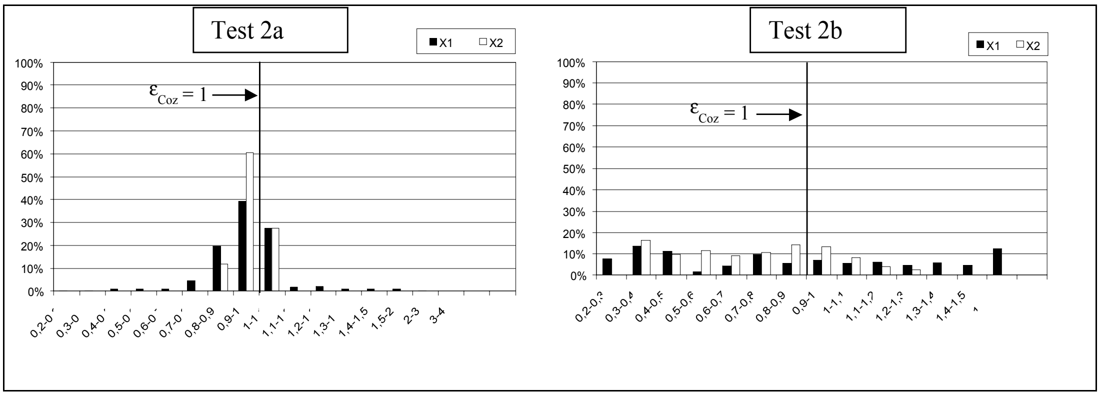

Figure 4: Ventilation effectiveness ε_{Coz} distribution in isothermal conditions, with 1ach/h

Tests With a Heating System

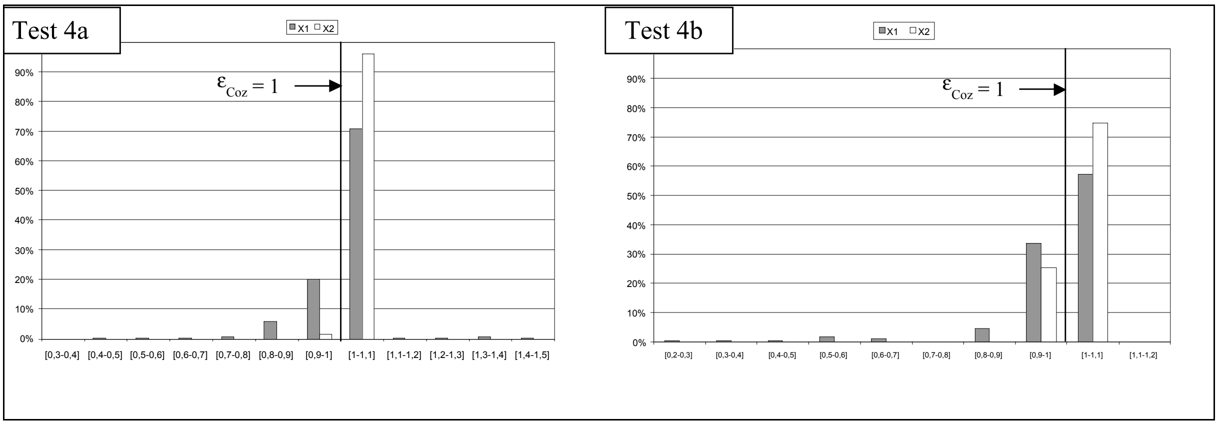

Figure 5: Ventilation effectiveness ε_{Coz} distribution with a convector

The ventilation effectiveness is closed to 1 for tests 4, 5, 6, 7, and 8. The heating system favours the mixing of the air, and makes the concentration homogeneous all over the cell, whether the air extract flow is. It should be noticed that concentrations values are higher in the case of a 0.5 vol/h extract air flow, than in the case of a 1vol/h extract air flow. More the extract are flow increases, more the pollutants are diluted. That seems logical.

The results are not significantly affected by the presence of the manikin, and the extraction position has little influence on ventilation efficiency. The air in the room is well mixed and gas concentrations are homogenous due to the action of the heating, even if the power of the system is only of 310 W.

CONCLUSIONS

In isothermal conditions, extract air flow has an influence on ventilation effectiveness. In the contrary, a slightly influence has been noticed when an heating system is included. The heating favours the mixing of the air in the cell, and so, the ventilation effectiveness is equal to 1. However, in these cases (including a convector), the extract air flow has an influence on the pollutant dilution: more the extract air flow is important, less the pollutant concentration in the cell is elevated. Otherwise, this study shows the importance to define a new ventilation index including, not only the pollutant concentrations in the cell, but also parameters like pollutant density or the configuration of the ventilation system (extract near the ceiling or the ground, …). Test 3a in isothermal conditions particularly shows this. In a same way, it could be interesting to study how to take into account the pollutant stagnation near the ground. Currently, the ventilation effectiveness is obtained from the calculation of a mean. But, it could be considered, for example, as the weighting of some measurement points, or as a method including particular points of the studied domain.

These experiments could be used in the validation of zonal or CFD codes. And the experimental data base could provide a starting point for other calculations using different configurations (ventilation systems, heating systems, dimensions, etc.).

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