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A NUMERICAL STUDY ON POLLUTANT REMOVAL EFFECTIVENESS OF A ROOM

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ABSTRACT

Ventilation system has to be design in order to strike a balance between indoor air quality and energy requirements. So, the ventilation efficiency can be considered as a major issue to deal with this objective.

In order to assess the efficiency of pollutant elimination from a room, a methodological approach using CFD has been developed. It is based both on local and global indexes. These indexes take into account the distribution of pollutant concentration inside room and the mean concentration at the exhaust with respect to the occupant location.

Based on an isothermal two dimensional test case of IEA Annex 20, a sensitivity analysis has been carried out to calculate the pollutant concentration with regards to the exhaust vent and pollutant source locations. The results obtained with the above-mentioned indexes have shown that each configuration can be characterised in connection with the efficiency of pollutant elimination. In addition, these indexes show how the connected location of both exhaust vent and pollutant source affects the indoor air quality.

KEYWORDS

Ventilation efficiency, numerical simulation, contaminant removal effectiveness.

INTRODUCTION

The main objectives of ventilation in buildings are to provide fresh air and to extract pollutants from occupied zones. Levels of air removal are generally based on occupants needs but could be insufficient to dilute correctly pollutants from internal sources.

It is important to optimise the ventilation system in regard with extraction of pollutants in order to ensure a good air quality for occupants. In addition, ventilation system must be dimensioned such as energy consumption is minimised.

Experimental approaches with tracer gas are actually used with success to study ventilation efficiency in buildings. However, it is quite difficult to bring them into operation and to perform parametrical studies. So, numerical simulation using CFD codes offers theoretically good prospects for studying ventilation efficiency.

This paper, with the use of CFD Phoenics code, proposes a methodological approach to qualify removal effectiveness of a room. Air quality indexes are presented and are applied to a case study on which a parametrical study was conducted.

VENTILATION EFFICIENCY INDEXES

Ventilation efficiency is a well-known concept that includes a set of indexes and parameters to characterise air change efficiency and contaminant removal effectiveness. International literature describe well enough these aspects, and for example an A.I.V.C. note from Liddament (1993). In this paper, two indexes are presented. They enable to characterise pollutant removal for a given configuration (geometry of the room, position of inlet and outlet, level of air change rate, position of source of pollutant), from a local or a global point of view.

The local air quality index IQ and the contaminant removal effectiveness ε_p are here defined respectively as following :

$$IQ = C_p / C_e \qquad (1)$$

$$\varepsilon_p = C_m / C_e \qquad (2)$$

with : C_p : concentration of pollutant at a given point P,
C_m : mean concentration of pollutant for a given zone,
C_e : mean concentration of pollutant at the exhaust.

These definitions are here the inverted values of the indexes usually used in the litterature, for example Brouns and Waters (1991). That makes easier to identify the poor air quality area. We can notice that the lower are the indexes, the better is the removal effectiveness.

CASE STUDY

We used an isothermal two dimensional experimental test case of Nielsen, Restivo & Whitelaw (1978) issued from the I.E.A. Annex 20 (1993). The airflow rate is 10.3 a.c.h. and experimental results are provided for longitudinal velocity and turbulence intensity for AA, BB and CC lines (see figure 1).

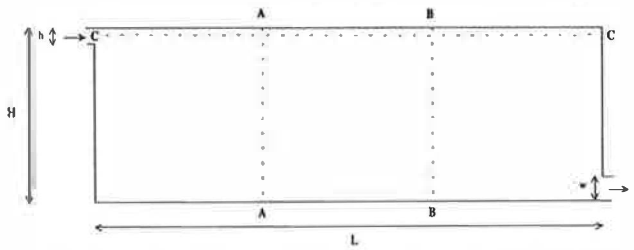
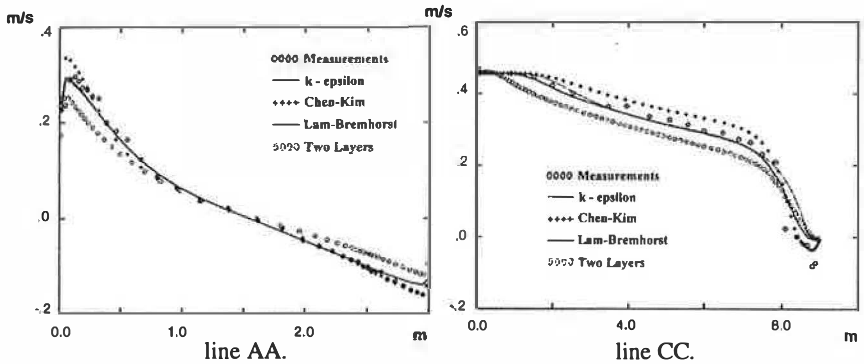


Figure 1 : Configuration of Annex 20 isothermal two-dimensional case study.

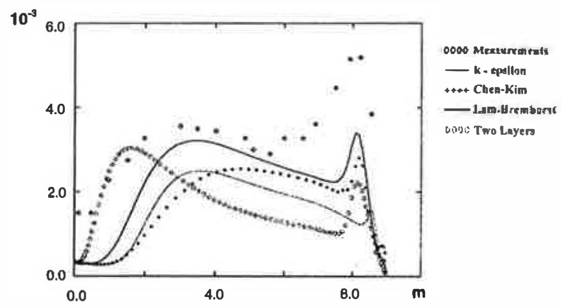
Comparison with experimental data

We have used the CFD code Phoenics and tested several k-ε turbulence models : k-ε standard, two layers model, Chen-Kim low Reynolds model and Lam-Bremhorst low Reynolds model. We present below some of the results obtained with these models in confrontation with experimental results from Nielsen. Even if Chen-Kim model overestimates the longitudinal velocity in the air jet, it is the one which represents better the recirculating zone observed in the experiment (figure 2). Turbulence energy calculated with this model is qualitatively good compared to others calculations and experimental results (figure 3). The convergence is easier with this model than with Lam-Bremhorst model. That is why we have used Chen-Kim model for the following study.



line AA. line CC.

Figure 2 : Longitudinal velocity (in m/s), confrontation between experimental and numerical results for several turbulence models.



line CC.

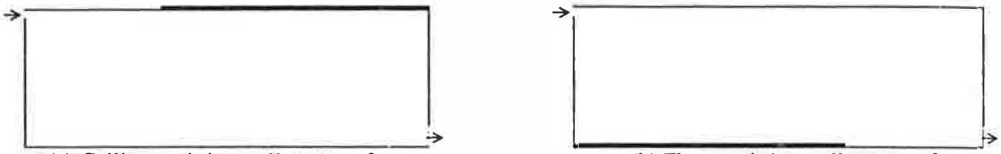
Figure 3 : Turbulence intensity, confrontation between experimental and numerical results for several turbulence models.

Modelling of transfer pollutant

To model transfer of gaseous pollutant, we calculate the concentration field solving the following transport equation applied for a two dimensional case :

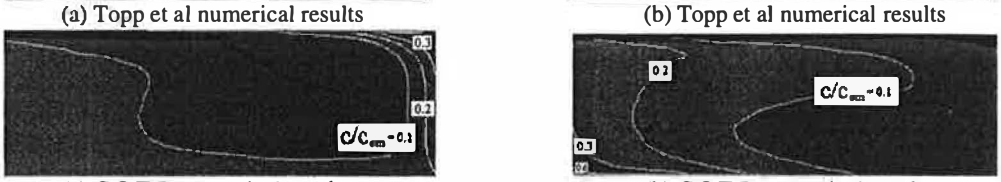
$$\partial C/\partial t + U\,\partial C/\partial x + V\,\partial C/\partial y = D\,(\partial^2 C/\partial x^2 + \partial^2 C/\partial y^2) \qquad (3)$$

For this calculation which is strongly convective, we can neglect the airflow movement due to gradient concentration. Numerical calculations have been conducted using the configuration presented in figure 1 with emitting pollutant surface expressed in constant concentration as boundary conditions, and located either at the ceiling or at the floor. Figure 4 shows our results compared with numerical results obtained by Topp, Nielsen & Heiselberg (1997).



(a) Ceiling emitting pollutant surface (b) Floor emitting pollutant surface

(a) Topp et al numerical results (b) Topp et al numerical results



(a) C.S.T.B. numerical results (b) C.S.T.B. numerical results

Figure 4 : Comparison of concentration distributions for two configurations (a) Ceiling emitting pollutant surface (b) Floor emitting pollutant surface.

The values showed in figures represent the ratio between local concentration (C) and concentration at the emitted surface (C_{em}). We can observe that the concentration patterns are quite identical. Nevertheless, our calculations show a more important transport of pollutant. These differences could be explained by different modelling conditions such as turbulence model.

PARAMETRICAL STUDY

On the basis of case study presented in figure 1, we have carried out a parametrical study on location of pollutant source in connection with the location of the exhaust as shown in the figure 5.

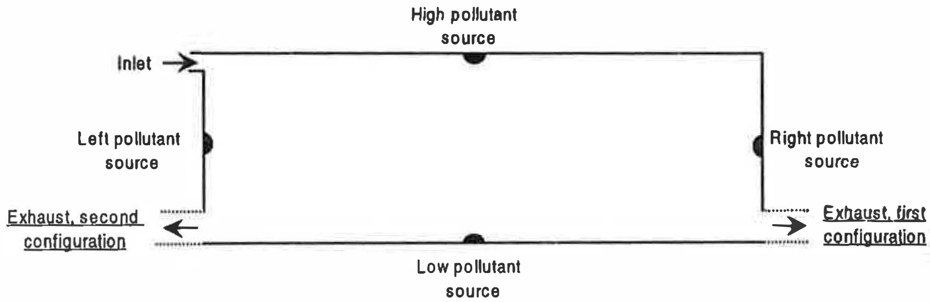


Figure 5 : Different configurations for parametrical study.

Whatever is the location of pollutant source, its modelling is always the same : a slightly airflow rate ($8.5\ 10^{-5}\ m^3/s$) with a concentration of 100 ppm.

Figures 6 and 7 show results obtained for the both configurations of the exhaust.

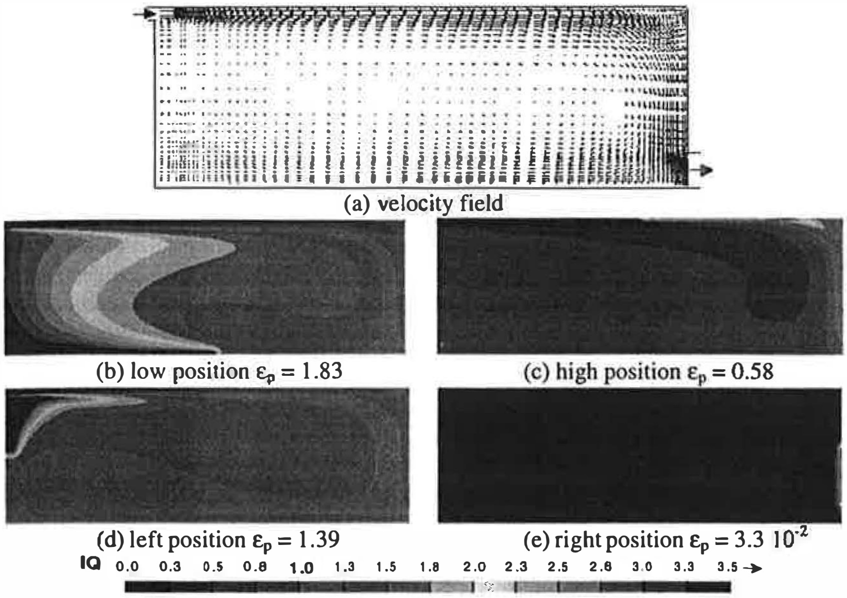


Figure 6 : First configuration of exhaust, (a) velocity field, (b to e) IQ field for the different position of pollutant source.

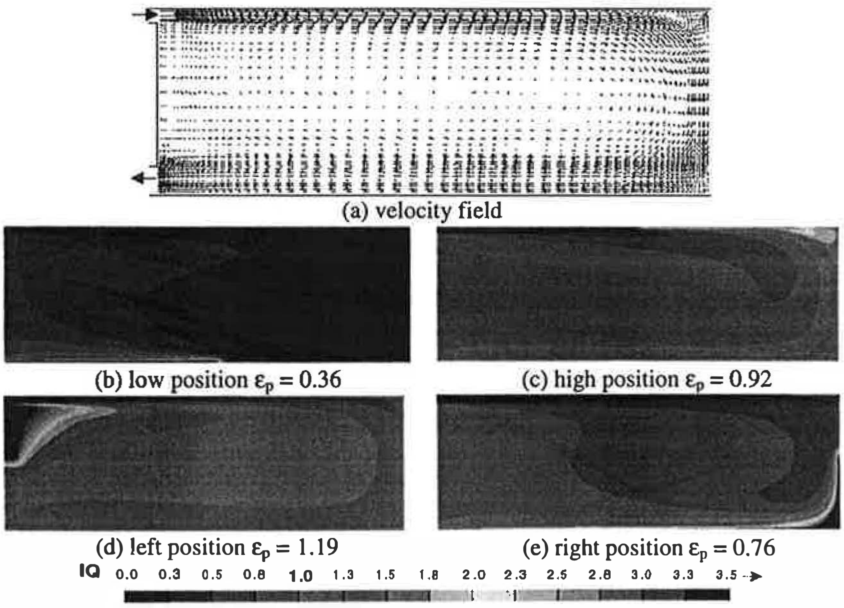


Figure 7 : Second configuration of exhaust, (a) velocity field, (b to e) IQ field for the different position of pollutant source.

Due to the magnitude of the supply airflow rate, the airflow pattern is not disturbed by the pollutant source airflow. That is why, for a given configuration of the exhaust, the effect of the location of pollutant source can be assessed. In both configurations, the flow sticks the wall especially in the second configuration. In the first configuration, a greater recirculating zone is observed. For these calculations, the contaminant removal effectiveness ε_p has been calculated on the overall domain.

For a given ventilation system, the calculation of ε_p enables to grade the efficiency of pollutant elimination with regard to the location of pollutant source. For the first configuration, high and right locations of pollutant source are closed to the exhaust, so pollutant is directly removed. In these two cases, the values of ε_p are lower than 1. It reflects a good air quality within the occupied zone. Low and left locations of pollutant source lead to a transport of pollutant in the recirculating zone. In these two cases, the values of ε_p are higher than 1. It reflects a bad air quality within the occupied zone. A similar analysis can be done for the second configuration where low, high and right positions of pollutant source lead to an ε_p lower than 1, and left position of pollutant source to an ε_p higher than 1.

ε_p can also contribute, for a given location of pollutant source, to assess the ability of ventilation system to remove pollutant. For example, in our case, when pollutant source is located on left position, pollutant is transported in the recirculating zone, and the air quality is poor, but better in the second configuration.

CONCLUSION

Numerical simulation using CFD codes offers theoretically good prospects to quantify ventilation efficiency. A methodological approach has been developed and applied for a parametrical study. Indexes used enable to grade the efficiency of pollutant elimination with regard to the location of pollutant source and help to design the ventilation system.

However, the use of these numerical tools needs to make efforts to validate the thermal and aerodynamic fields, and to model pollutants emission and transport. Further works are also needed to apply CFD simulations on complex geometries and for unsteady flows.

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