OPTIMUM VENTILATION AND AIR FLOW CONTROL IN BUILDINGS

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(Title)

Zonal Model to Predict Air Distribution and Dynamic Concentration of Pollutant in Ventilated Rooms

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Synopsis

The first part of the paper will show some aspects of experimental research on air distribution in ventilated rooms. The study has been carried out to get an understanding of the air movement and the ventilation effectiveness by means of tracer gas measurements. It has been investigated the velocity and the distribution of the concentration in a two-dimensional isothermal flow issue of a linear supply opening.
The second part of the paper will describe a proposed zonal model in 9 zones. This model is able to predict the steady-state behaviour of ventilated rooms and the dynamic evolution of a possible pollutant concentration in such environment. The theoretical model is based on the flow element method according to the throw of an isothermal jet and on a typical configuration of a zonal model.
Comparisons between experimental measurements and the zonal model results show a good agreement on the range of usual air change rate in the ventilated rooms.

1. Introduction

One of the purpose of a ventilation system is to produce optimal conditions for occupants. Understanding room air distribution is essential for the design of ventilation systems and control of the room thermal comfort and air quality conditions.The air motion within a room affects the thermal stratification and the contaminants distribution and therefore establish the air quality available to the occupants.Modelling and predicting contamination transport within the rooms or buildings could supply the effectiveness of ventilation and choose the best solution in design.

In the last years strongly efforts have been concentrated on problems of flow patterns, measurements and simulations. The results of the performed work have been published by AICV and by other scientific teams too. But, the difficulty of the problems and the large range of applications, each with its particularity makes impossible for the moment a general solution to be used by the design engineer.
Therefore, this paper describes an experimental and theoretical study on isothermal ventilated room, proposing a zonal model to predict air movement and pollutant distribution. Measurements and simulations have been carried out by the author in France, at the University of La Rochelle and the subject has been included in the objective of National Action of Research " Qualite de l'air dans les batiments ", beginning in 1994 by CNRS within the ECOTECH programme.

2. Experimental study

The aim of experimental study was to provide information and quantitative data, such as velocities and concentrations, of the air movement generated by an isothermal linear jet. These results were used to check the theoretical solution provided by the zonal model.

The experiments were make in a full-scale model. The geometry of the test room and the dimensions of the linear diffusers are such as given a steady two-dimensional flow in the main body of the room.

The geometrical dimensions are:

test room : L x B x H = 3,50 x 1,00 x 2,50m
linear diffuser : B x h = 1,00 x 0,005m

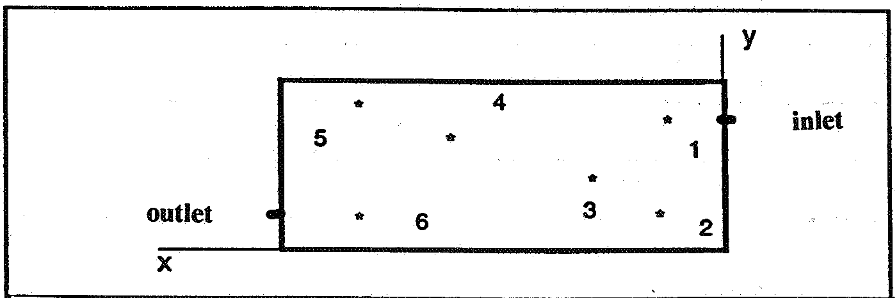
The supply opening was placed at 0,50m from ceiling and the dimensions of the test room were choose to enable the development of a free jet.

The primary purpos of these model experiments was to obtain knowledge of the air distribution in the room for varied flow rate and velocity in the supply diffuser.
Three types of measurements were performed:

a) air distribution in the room;
b) supply velocity and velocity on the axis of the jet;
c) temperatures on the walls of the test room.

Flow rate was established in the range of usual building ventilation: n = 1...10 Vol/h, that means: u_0 = 0,57....5,4m/s, velocity in the supply opening.

a) Air distribution was measured by means of tracer gas technique.It was employed a single tracer gas technique and the constant injection method. The traser gas was SF6. Since, the development of the air movement are bidimensional and symmetrical, the points of prelevation tracer gas were placed in an axle plan like in figure 1. The values of concentration were recorded during all the time of experiments. The graphs of concentration in SF6, is show in figure 2 and 3, for two flow rate: n = 1Vol/h and n = 10Vol/h (u_0 = 0,57m/s and u_0 = 5,4m/s).



points of measurement	1	2	3	4	5	6
x [m]	0,5	0,5	1,00	2,50	3,00	3,00
y [m]	1,90	0,5	0,95	1,80	2,10	0,50

Figure 1. Points of prelevation traser gas

b) The supply velocity is established by means of a micromanometer tube Pitot. Test measurements show that the linear opening gives an uniform distribution of air velocity on its surface. In order to pick up the information on jet development, the velocity was measured in the axis of the jet, in point 1.
Theoretical, velocity in the axis of a plane jet is calculated with the following equation:

$$u^*_{ax} = \frac{u_{ax}}{u_0} = x^{*^{-\frac{1}{2}}} \left(\frac{2k'}{\pi}\right)^{\frac{1}{4}} \qquad (1)$$

where:

$$x^* = \frac{x}{h}$$

$$k' = \frac{k}{\left(1 + \frac{690}{\mathrm{Re}}\right)^2} \qquad \text{for Re} < 10^5$$

and k is a linear diffuser coefficient.

Checking the calculated velocity and measured velocity in the point 1, we have the table 1.

Table 1. Calculated and measured velocity in the point 1, x = 0,50m

u_0 (m/s)	Re	k'	u_{calc} (m/s)	$u_{măs}$ (m/s)
0,57	190	2,33	0,062	0,06
0,85	283	4,24	0,108	0,10
2,04	680	12,32	0,340	0,24
2,58	860	15,39	0,454	0,36
3,10	1033	17,98	0,568	0,40
3,91	1303	21,38	0,748	0,27
5,40	1800	26,13	1,086	0,31

The results show the followings :

1. - for u_0 = 0,57m/s to u_0 = 1,0m/s (low flow rate), it's a good agreement between calculation and measurement at a distance x = 0,50m from the supply opening;

2. - for u_0 > 1,0m/s, occurs a deflection of the jet due to the Coandă effect. The air jet sticks, after some distance, to the ceiling and after another distance it detaches creating a quite

rapid rotating movement below it. This is one of the principal reason of air distribution in the room. More information and details on experimental study were given in [4], [5].

c) Surface temperatures are measured by 0,2mm chrom-aluminium thermocouples and the temperatures were recorded. The difference between the six surface temperatures of the test room was lower that 1 ° C. This boundary decay of isothermal state did not alter the general stream line pattern within the room. In the region of developed turbulence the inertial forces are dominated against the thermal forces and molecular diffusion.

3. Numerical prediction of the air movement

The prediction method presented in this paper is based on general main assumptions of zonal model:

- the ability to predict the main driving flow (boundary layer, jet or thermal plume);
- experimental and empirical knowledge to describe particular processes.

The performed work and results of zonal models have been presented within the frame of IEA Annex 20 and in the scientific communications [2], [3].

Our zonal model in nine controller zones, presented in this paper, is able to predict the air diffusion and pollutant distribution in a room ventilated by an isothermal linear jet.
In order to compare the predicted and measured results, we have kept the same boundary conditions like in the experimental study: flow rate, geometry of the room and diffuser. We considered that the bottom zone of the room is covered by the isothermal jet which is the main driving flow. All other zones were assumed like " current zones " as shown in figure 2.

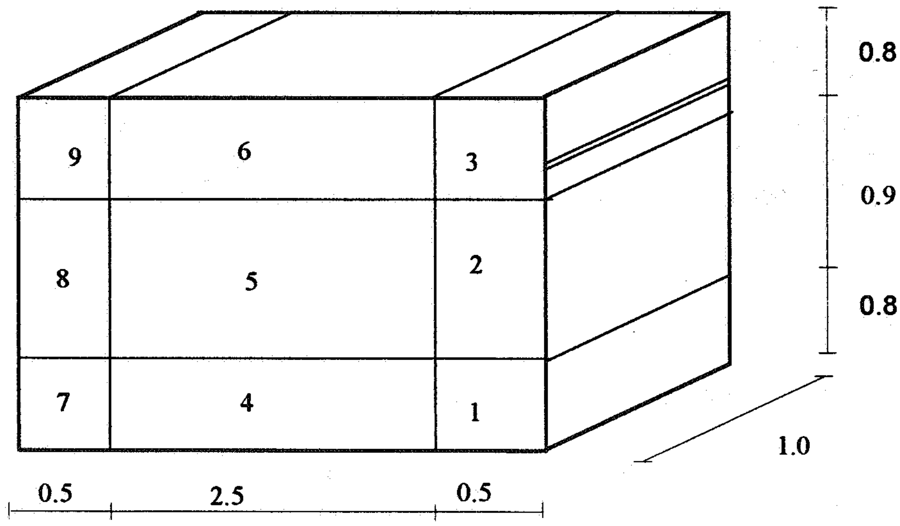


Figure 2. Theoretical room division

3.1 Characteristic equations

Knowing the air jet behaviour and considering the theoretical borders been permeable, we have proposed the air movement sketch as shown in figure 3.

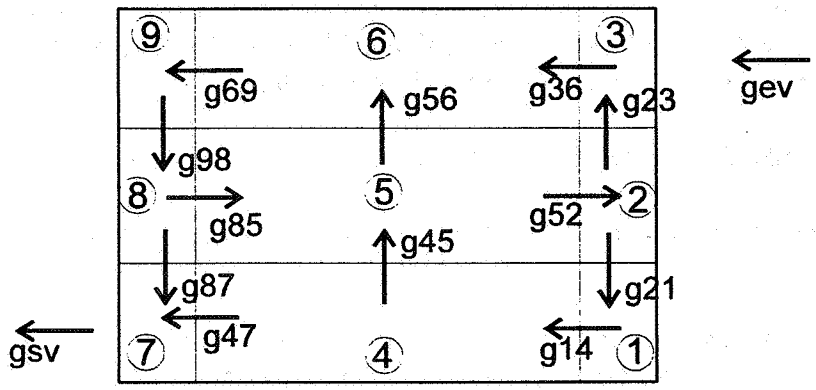


Figure 3. Sketch of air movement

a) Steady-state equations

The inside air volume is divided into nine isothermal zones coupled with mass conductance. For each zone the mass balance is written:

$$\sum_j g_{ij} + g_{Pi} = \sum_j g_{ji} + g_{Si} \qquad (2)$$

To complete the system of equations other four equations must be given or identified. Jet flow equations supply mass flow through 3 - 6 and 6 - 9 borders.. We assume that the mass flow variation in the zones 2 and 7 is proportional with an entrained coefficient Kj:

$$g_{ij} = \frac{A_{ij}}{\sum A_{ji}} g_s = K_i g_s \qquad (3)$$

and Aij is the surface of the borders. So, we have the mass flow g47 and g52.
Solutions of equations (3) are the mass flows through theoretical borders.
The corresponding velocities are calculated with the equation of continuity:

$$g_{ij} = \rho_i u_{ij} A_{ij} \qquad (4)$$

b) Unsteady-state equations

The air movement in the room is permanently for each supply flow rate, but the evolution of a pollutant concentrations is unsteady.
For an air volume crossed by mass flow gij, which drive a pollutant concentration Cj, the local variation of concentration Ci can be calculated :

$$\rho_i V_i \frac{dC_i}{dt} = \sum g_{ij} C_j \qquad (5)$$

This differential equation written for a control volume can be replaced by a difference equation:

$$\frac{dC_i}{dt} = \frac{C_i^{t_n} - C_i^{t_n - 1}}{\Delta t} \qquad (6)$$

The moment value of concentration is considered uniformly within a volume. This concentration is calculated function of the neighbourhoods concentrations and the previous local concentration :

$$C_i^{t_n} = C_i^{t_n - 1} + \frac{\sum g_{ij} C_j^{t_n}}{\rho_i V_i} \Delta t \qquad (7)$$

The nine differential equations are replaced by nine difference equations generating a matricial system :

$$[A]x[X] = [B] \qquad (8)$$

This system was solved by means of Gauss method.
For solve the steady-state and unsteady equations, it was need to create a numerical programme named by author, CONNY. Figures 4 and 5 show the values of velocities through borders for n = 1Vol/h and n = 10Vol/h, respectively, compared with a k-ε simulation. Figure 6 presents the concentration profile obtained by numerical simulation using CONNY programme and by measurements recorder.

Following remarks are presented:
- using a k-ε numerical simulation for the same boundary conditions we have obtain isovelocity curves. The distribution and the values of this curves enable us to declare available the sketch of mass flow distribution;
- comparing the measured and calculated concentration graphs we observe the general evolution on the same values and the same maximal value attained. For the smaller flow rate, n < 4 Vol/h, the numerical profile has a deviation roughly 10% compared with the measurement graph. For n > 4 Vol/h, the two profiles are following the same values.

4. Conclusion

For the usual ventilated rate in civil buildings, n = 1..10Vol/h, the nine zonal model described in this paper proves its ability to predict air distribution (mass flow and velocities) and concentrations in a room. Taking into account the ahead observations, this zonal model can be a tool for the design engineer in HVAC. But, its application is limited to the rooms ventilated by an isothermal plane jet. We intend to develop this zonal model, changing the type of jet and his thermal state. Also, we study the possibility to apply this zonal model to predict the behaviour of a heated and ventilated rooms.

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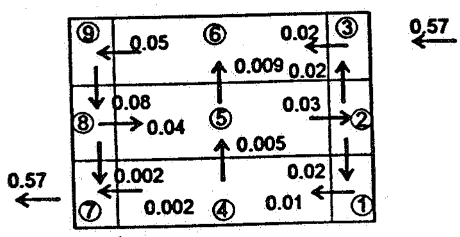
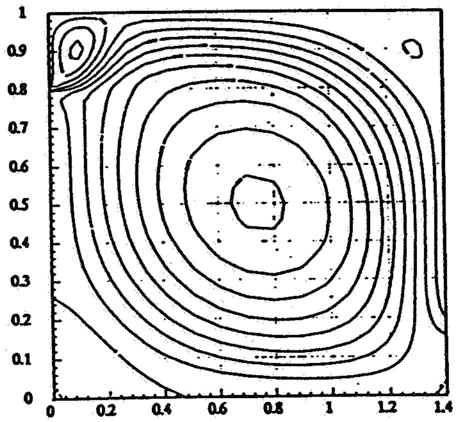
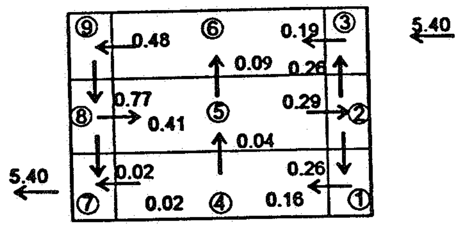
8. *** ***Annex 20 . Air flow Patterns within Buildings. (1993)***
International Energy Agency

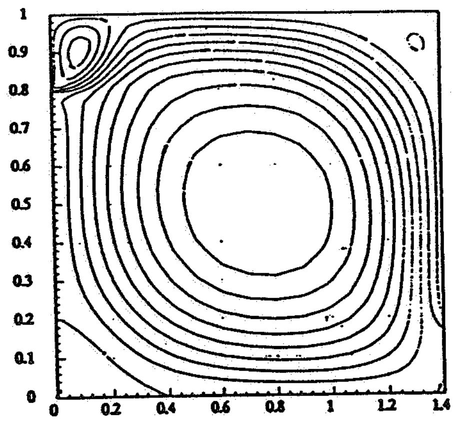




a) velocities predicted by zonal model b) isovelocities, k-ε simulation

Figure 4. Air movement in room, n = 1Vol/h





a) velocities predicted by zonal model b) isovelocities, k-ε simulation

Figure 5. Air movement in room, n = 10Vol/h

gev= 1.288333E-02

Measuremed concentrations

7620
Gaz Traceur
Mesures

REGLAGES:		INFORMATION GENERALE:		COMMENTAIRES:	
Interval. Echant.:	Cont.	Heure Debut:	1994-06-23 14:40	T=43,9 Volt	
Interv.Temps mesure:	238 s	Heure Fin:	1994-06-23 17:30	Vo=2,58 m/s	
Temp. de normalis.:	293.1 K	Temps Compression:	Aucun	Q=46,44 m3/h	
Compens. croisee:	Non	Defauts:	Oui	N=5,28 Vol/h	
Compens Vapeur d'eau:	Non	D. Editees:	Non	DONNEES:	JUIN23PM
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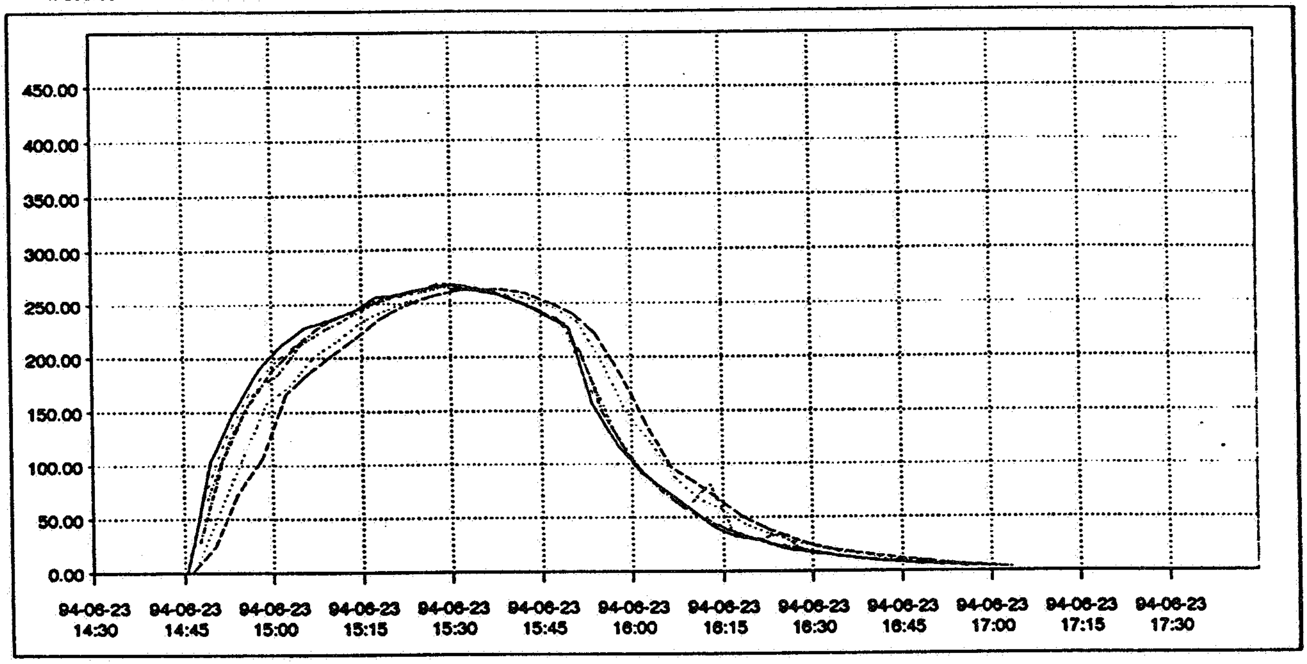

C	Position:	Mesures	Trace Ech.	Unite	Vol.Piece
1	Voie 1302	GAS UA0988	1E+00	mg/m³	8.80 m³
2	cellule	GAS UA0988	1E+00	mg/m³	8.80 m³
3	cellule	GAS UA0988	1E+00	mg/m³	8.80 m³
4	cellule	GAS UA0988	1E+00	mg/m³	8.80 m³
5	cellule	GAS UA0988	1E+00	mg/m³	8.80 m³
6	cellule	GAS UA0988	1E+00	mg/m³	8.80 m³

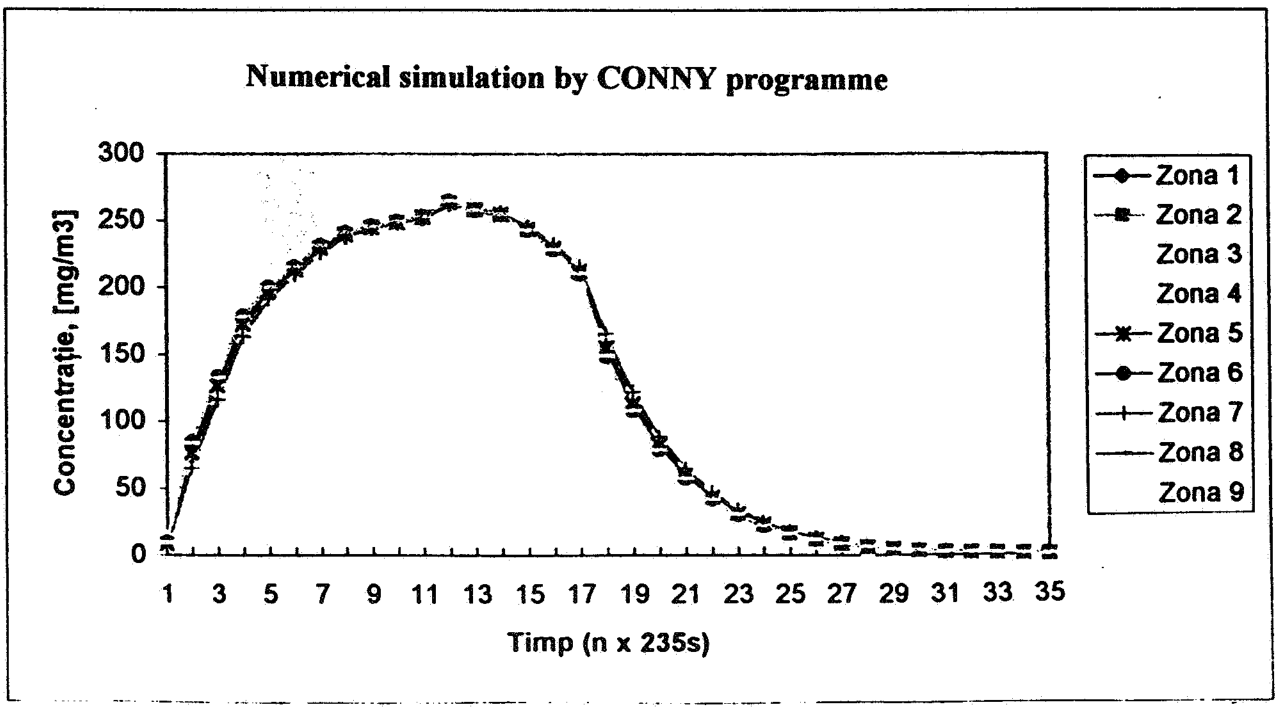

Figure 6. Local concentration measured and calculated by zonal model, n = 5 Vol/h