VENTILATION EFFICIENCY IN DWELLING CELLS : CONTRIBUTION TO THE VALIDATION OF A ZONAL MODEL

S. Castanet[1], H. Bouia[1], A. Duta[1] and C. Inard[2]

[1]CETHIL, INSA de Lyon, Villeurbanne, France
sophie@parga.insa-lyon.fr, hassan@parga.insa-lyon.fr, anca@parga.insa-lyon.fr
[2]LEPTAB, Université de La Rochelle, La Rochelle, France
cinard@cri.univ-lr.fr

ABSTRACT

Since reduction of ventilation rates in dwellings for economical reasons, it has been necessary to study whether this reduction had not been done to the detriment of indoor air quality. Several means of investigating were developed : experimental tests are indispensable but usually expensive that is why numerous research centres choose to model the thermoconvective fields in rooms. During the last 2 decades, considerable effort has been made to overstep the notion of isothermal air volume because it does not allow to compare heating and ventilating systems, especially with regard to thermal comfort, energy consumption and indoor air quality.

The zonal model which is used at the CETHIL (Thermal Physics Centre of Lyon) is a simplified and inexpensive alternative to CFD models which are time consuming and more difficult to apply.
This model has been used to assess a ventilation system in which ventilation rate, external temperature and temperature difference between air supply and occupancy zone were varied.
The calculations were carried out for the test cell, Minibat, which measures 3.1 × 3.1 × 2.5 (m^3).
Results were then compared to a campaign of measurements on the real size test cell Minibat.

KEYWORDS

Zonal model, Ventilation efficiency, Temperature efficiency, Full-scale experiments, Tracer gas.

Nomenclature

C :	concentration
$C_{upstream}$:	entering concentration coming through j frontier
m_{ij} :	mass flow rate between two zones i and j (towards i zone, through j frontier)
ms :	supplied air mass flow rate
me :	exhausted air mass flow rate
P :	zone pressure
P_{conv} :	convective heat power of emitter
P_{tot} :	total heat power of emitter
qi :	local source of pollutant
T :	temperature

GENERAL STRUCTURE OF THE ZONAL MODEL « SAMIRA »

The principle of zonal models is to divide the air volume into isothermal macro-volumes and to write mass and thermal balances for each of them so as to evaluate fields of velocity, temperature and concentration of pollutant in the air. The method used consists, then, in calculating an indoor pressure field using a "degraded" equation for the momentum allowing a mass air flow between 2 zones to be connected to the corresponding pressure differential.

The domain under consideration is broken up into n isothermal zones according to a parallelepiped type geometry, see Figure 1. All these zones are inter-connected by mass air flows and the mass and thermal balances are given for each of them. For the mass balance, we write Eqn. 1 :

$$\sum_{j=1}^{n} m_{ij} + ms_i = \sum_{j=1}^{n} m_{ji} + me_i \qquad (1)$$

The thermal balance under steady state conditions is expressed by Eqn. 2 :

$$\sum Cpm_{ij}(T_i - T_j) + Cpms_i(T_i - Ts_i) + \Phi_{conv\,i} = P_{conv\,i} \qquad (2)$$

And pollutant species conservation equation is written as follows (Eqn. 3) :

$$\sum_{j=1}^{6} m_{ij}\, C_{upsream} = q_i \qquad (3)$$

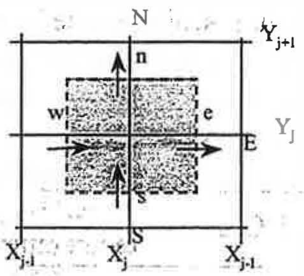


Figure 1 : Example of control volume

Consequently, if we express the convective heat fluxes exchanged along the walls as a function of air temperatures, we have n independent equations for the thermal balance associated to n-1 equations for the mass balance. Generally speaking, we actually have n+n(n-1) that are unknown. The difference between the number of available independent equations and the number of unknown quantities is due to the fact that we do not use the equations of momentum conservation. To settle the problem and to obtain a rapid approximate method, we distinguish two types of zones:

(i) the current zones,
(ii) the specific flow zones.

We thus choose a different procedure for each type of zone to calculate the air mass flows exchanged between two zones. Further descriptions of the model are given in Inard et al. (1996).

DESCRIPTION OF THE TESTS AND PRESENTATION OF THE CELL

Numerical calculations were performed for a cell measuring 3.1 × 3.1 × 2.5 (m^3). Calculations were processed for a 3D-300 node mesh. The supply grille is under the ceiling, on the "south" side. Two configurations of ventilation were tested, according to 2 exhaust positions; both are opposite supply side. The first one (configuration A) is under the ceiling and the second one is on the floor (configuration B), see Figure 2.

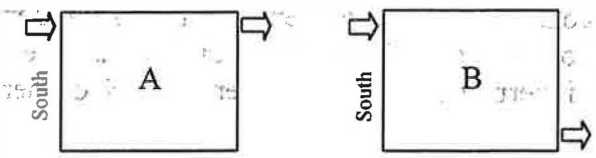


Figure 2 :Tested positions of supply and exhaust.

Wall temperature boundary conditions were set according to experimental conditions (see Table 1) that is to about 20 °C except for 'South' wall. The air renewal was set to 1 air change per hour and tests were performed for 2 air supply temperatures : one case of warm supply and one case of cold supply (See Table 1).

Besides, a pollutant source (SF_6) was settled at the geometrical centre of the room with a constant flow rate of 0.5 ml/s.

In the mean time, we performed the experimental tests corresponding to these numerical cases.

The experimental set up is the full scale test-cell, "Minibat", see Figure 3. It is made of 2

TABLE 1
Conditions (numerical and experimental) of performed tests

CONFIGURATION	Case	Air supply temperature (°C)	'South' wall mean temperature (°C)
A	1	33.5	18.9
	2	11.1	24.5
B	1	34.0	19.6
	2	11.2	24.9

identical rooms (Zone 1 and Zone 2) which measures 3.1 x 3.1 x 2.5 m^3, each. A thermal guard maintains an uniform temperature all around the cell. One side of the cell, called 'South' side, is made of glass and is in contact with a climatic housing.

Necessary boundary conditions were accurately monitored for each test. A pollutant source continuously injects tracer gas (SF_6) at the centre of Zone 1.

An automatic system scans the vertical mid plane of each zone so that temperature and velocity of the air and SF_6 concentration are measured. The regular grid has an elementary mesh of 0.1 × 0.1 (m^2). Tests were made in thermal and concentration steady states.

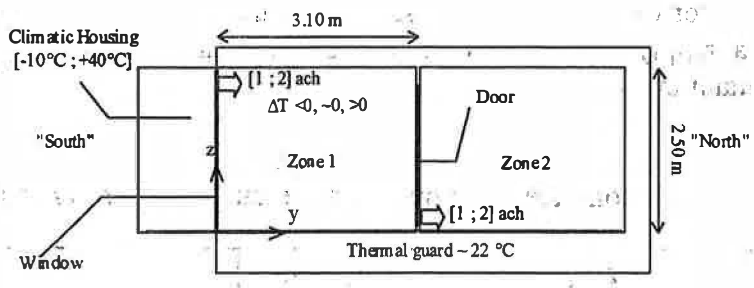


Figure 3 Experimental test cell "Minibat".

Results

In order to assess ventilation systems, temperature and ventilation efficiency were calculated. Temperature and ventilation efficiency (Sandberg, 1981; Qingyan et al., 1988), ε_T and ε_C, express the ability to respectively remove heat and pollutants. They respectively depend on measurements of temperature (T) and concentration (C) taken at supply (s), extract (e) and on the mean value in the occupancy zone (oz). They are expressed with Eqn. 4 and 5 :

$$\varepsilon_T = \frac{T_e - T_s}{T_{OZ} - T_s} \tag{4}$$

Regarding pollutant removal, in this work, the pollutant source is placed at the centre of the room; this thus implies that Cs = 0. Ventilation efficiency is therefore expressed as follows :

$$\varepsilon_c = \frac{C_e}{C_{OZ}} \tag{5}$$

Besides, temperature and velocity of the air and SF_6 concentration were processed in order to display isovalue lines.

DISCUSSION

Results of tests are committed to Table 2. First of all, it appears that, on the whole, the model is good to predict temperature efficiency. Temperature profiles taken in the middle of the cell (See Figure 4) even show that this prediction is quite good even locally.

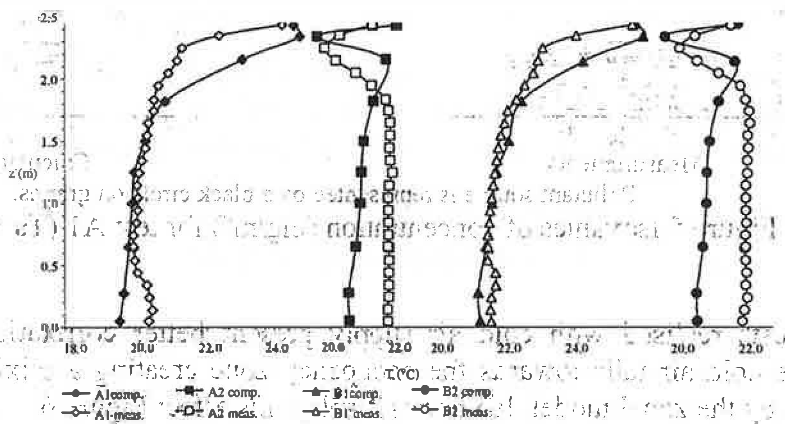


Figure 4 Air temperature profiles at the centre of the cell for each test.

Nevertheless, the model it is not efficient to evaluate concentration efficiency. This is especially true for cases of warm air supply. Actually, as the air renewal is quite low (~ 24 m^3/h that is a supply air flow velocity of 1.33 m/s) air movements are not strong enough to mix the pollutant in the cell.

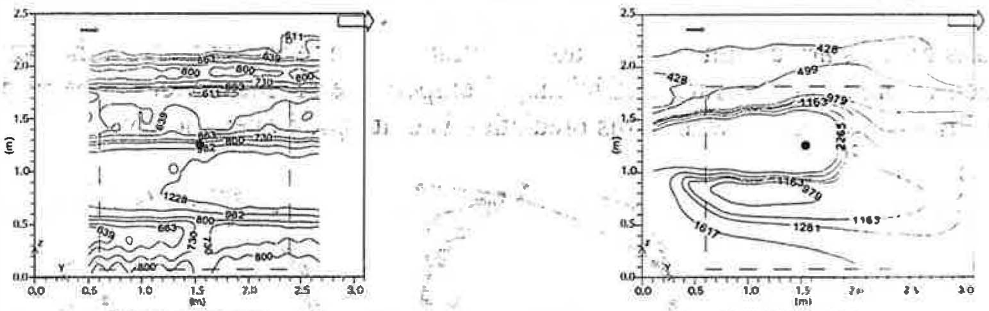
TABLE 2
Computed ('comp.') and Measured ('meas.') results.

TEST	Toz (°C)	T_e (°C)	ε_T	$\lvert\Delta\varepsilon_T\rvert$* (%)	Coz (mg/m^3)	C_e (mg/m^3)	ε_C	$\lvert\Delta\varepsilon_C\rvert$* (%)
A1 comp. (1P)	19.7	22.4	0.72	7.7	2239	372	0.17	71.7
A1 comp. (3P)	19.8	22.4	0.72	7.7	1432	372	0.26	56.7
A1 meas.	20.0	22.9	0.78		892	536	0.60	
A2 comp. (1P)	20.8	21.7	1.14	7.5	532	369	0.69	27.4
A2 comp. (3P)	21.0	21.7	1.10	3.8	440	369	0.84	11.6
A2 meas.	21.7	22.3	1.06		510	483	0.95	
B1 comp. (1P)	21.5	21.3	1.02	0	1262	339	0.27	
B1 comp. (3P)	21.5	21.3	1.02	0	687	339	0.49	
B1 meas.	21.6	21.3	1.02					
B2 comp. (1P)	20.7	20.8	1.01	3.1	510	355	0.70	32.7
B2 comp. (3P)	20.9	20.8	0.98	0	424	355	0.84	23.1
B2 meas.	21.9	21.8	0.98		546	570	1.04	

- *Relative difference to Value, V : $|\Delta V| = \frac{|V_{meas} - V_{computed}|}{V_{meas}}$
- 1P : T_{oz} and C_{oz} are calculated over the vertical mid plane of the simulated cell (that is over 1 Plan)
- 3P : T_{oz} and C_{oz} are calculated over the whole cell (that is over 3 Plans)

Measurements prove that there actually is a mixing effect which is partly due to diffusion phenomenon but the zonal model does not involve any consideration of this effect (See Figure 5).

Further description of the phenomena observed in the cell are given in Castanet et al. (1997).

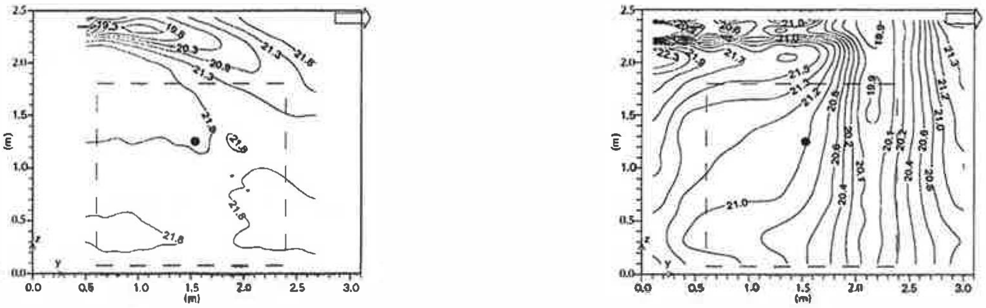


Measurements | Calculations

Pollutant source is represented by a black circle on graphs.

Figure 5 Isovalues of concentration (mg/m^3) for test A1 (Ts = 33.5 °C)

However tests realised with cold air supply present better correlation with experimental results : the cold air falls towards the occupancy zone creating a mixing effect that can be reproduced by the zonal model. Isotherms display this effect Figure 6.



Measurements Calculations

Figure 6 Isotherms (°C) for test A2 (Ts = 11.1°C)

Nevertheless, one may notice that, still, concentration efficiencies calculated with the model have the same evolution as those issued from measurements.

Calculations were drawn for a 3D configuration whereas measurements were only made in the vertical mid plan of the cell. One may see that temperature efficiency calculated with numerical results taken from one plan or from three plans are quite close. We may suppose that measurements made in the central plan are relevant to quantify the ventilation system in terms of temperature efficiency. However, estimation of concentration efficiencies is better when calculated from 3D results than from results of the mid plan.

CONCLUSION

Tests were performed in a full scale cell to compare results issued from calculations with zonal model. The model appeared to be good at prediction of temperature efficiency but, as it does not involve diffusion calculation, it cannot be used to describe concentration fields.

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