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Optibat: A Real Scale Cell in Simulated Climatic Environment for Multizone Air Flow Pattern in Building.

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ABSTRACT

One of the main problems about air flows pattern studies remains the experimental validation of numerical codes developped for interzone air flow and polluant diffusion prediction.

A few years ago, CETHIL developped a real scale experiment made of a $88m^2$ dwelling built in our laboratory hall in a controlled climatic environment. This experimental tool allows a full control of outdoor climatic conditions: air temperature, relative humidity, pressure drop can be controlled on the six faces of the cell: OPTIBAT is thus a reference tool for multizone air flow measurement techniques, and experimental data sets available for validation of numerical models.

The first phase of this experimental projet allowed us to determine air leakage characteristics of indoor and outdoor walls of the cell.

The second element required for the validation of multizone air flow codes is the knowledge of all the interzone air flows. The vast majority of the air flow measurements made to date have involved multiple tracer gas techniques. Using the OPTIBAT facility, we have first used only one tracer gas to determine all the air flows.

The present paper describes the experimental cell and gives the first results about air flows measurements using tracer gas technique. The interzone air flows are computed using two methods. Each method is completed by an error analysis which defines the uncertainty of each result. Both methods give the same results.

NOMENCLATURE

C	Tracer gas concentration matrix	
Cik	Tracer concentration zone i during the k^{th} test	$[m^3/m^3]$
q_{ij}	Air flow from the zone j to the zone i	$[m^3/s]$
Q	Air flow matrix	
Sik	Tracer source emission rate in the zone i during the k^{th} test	$[kg/s]$
S	Tracer source emission rate matrix	
Ti	Air temperature of the zone i	$[K]$
Vi	Volume of the zone i	$[m^3]$
X_i	Vector containing the six air flows q_{ij} coming to the zone i.	
Y_i	Vector containing the tracer gas rate injected in the zone i.	
σ_x^2	Variance of variable x	
δ_{ij}	Kronecker's symbol	

I. INTRODUCTION

A review of numerical codes about multizone air flow studies has been recently achieved for COMIS project [1]. This review shows that none of multizone codes now developped have been validated .

A few years ago, LASH, CETHIL, CETIAT, three laboratories located in the RHONE ALPES region, have developped together a multizone air flow study project . One of the main supports of this project is the OPTIBAT cell, an experimental tool for multizone air flow measurements to provide experimental data sets needed for validation of numerical codes. These data sets will also be included in Annex 23 of IEA.

We present here OPTIBAT and the first results of interzone air flow measurements obtained using tracer gas techniques.

I.1 Optibat: the experimental tool [2]

A few years ago, CETHIL developped a real scale experiment made of a $88m^2$ dwelling built in our Laboratory hall in a controlled climatic environment [3]. This apartment is in fact a part of a real building built near Lyon at this time

We split the apartment into 6 indoor zones as shown in the Figure 2.

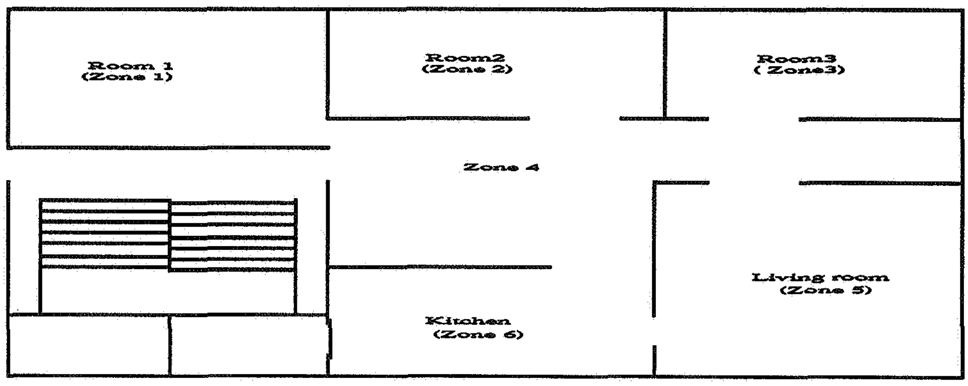

Figure1: The various zones of the experimental cell

To provide measurements under various controlled climatic conditions, climatic housings have been added to each face of the experimental cell (figure 3).

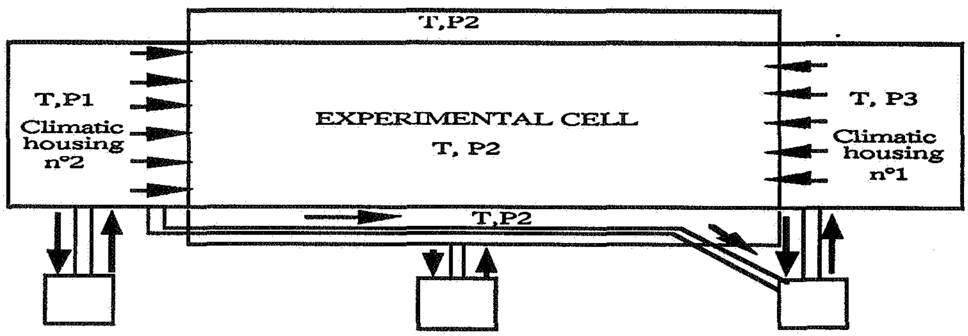

Figure 2: Schematic representation of the climatic conditionning principles

- On the two main façades, air temperature can vary between -10°C and 30°C, the pressure drop between the two housings can reach 200Pa. Relative humidity varies between 30% and 80%.

- On the other faces, a thermal guard simulates the adjacent apartments. Air temperature and pressure drop are also regulated.

I.2 The experimental project

Since its conception, this experimental facility has been mainly devoted to the validation of various thermal models developped by CETHIL. In order to use it as a reference experiment for multizone air flow studies, we had first to determine the leakage coefficients of all indoor and outdoor walls using two pressurisation methods [3]. Then, we until now, focus our attention on the interzone air flow measurements using tracer gas techniques. The first results of these measurements are presented here.

II. MONOGAS MULTIZONE TECHNIQUE

Most of multizone air flow measurements have involved multiple tracer gases[4, 5, 6]. In each zone a different tracer gas is injected. This needs as many tracers as zones. Whenever in monogas multizone technique, we use only one tracer to determine all the interzone air flows. The SF6 gas is injected at constant concentration using a PID regulation algorithm. The tracer concentration measurements are provided using a photoacoustic analyser. The measurements are done under steady climatic conditions: outdoor air temperature is controlled at 20°C, the pressure drop beetwen the main façades is equal to 100 Pa.

The principle of this multizone monogas technique is based on the repetition of the same test in each zone under the same climatic conditions. This is possible because all the climatic parameters can be controlled using the OPTIBAT climatic facility.

The six tests required to provide all the interzone airflows are the followings:

-1st test: the SF6 gas is injected at a constant concentration (10 PPm) in zone 1. A small fan (which air flow rate is 5 m^3/h) is installed just front of the injection tube in order to mixed the tracer gas and the volume air. The gas concentration is measured in all the six zones. When we stop the test, the indoor air is purged and taken out far from the hall in which OPTIBAT is built. During the purge the concentration of SF6 is measured in each zone until it becomes lower than 10^{-2} ppm.

-2nd test: After the purge, we injecte the SF6 at a constant concentration (10 ppm) in zone 2 and we repeat the previous operations under the same climatic conditions.

The test is repeated in each zone. Finally we made six tests under the same climatic conditions. During each test the tracer is injected in a different zone. This technique is equivalent to a multigas test using six tracer gases, each gas being injected in a different zone.

During all the six tests, air temperature is measured in 40 points in the building and in the climatic housings using RTD type PT100 probes. These probes have been calibrated in our laboratory and their accuracy is ± 0.05 C. The pressure drop beetwen each zone and outdoor is also measured.

The results of the measurements of the six tests are reported in Table 1. In upper part of this table, the values represent the mean concentrations of the tracer gas in each zone and in the lower part we represent the source emission rates.

Tracer gas concentration (ppm)						
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Test 1	9.74 ±0.51	0.08±0.008	0.09±0.008	3.58±0.08	2.85±0.11	3.59±0.10
Test 2	0.1±0.009	9.94±0.34	0.12±0.008	2.89±0.08	2.44±0.054	2.65±0.051
Test 3	0.09±0.01	0.11±0.01	9.97±0.23	3.42±0.11	4.98±0.09	3.54±0.09
Test 4	0.1±0.008	0.13±0.006	0.14±0.006	9.86±0.24	6.96±0.11	10.13±0.15
Test 5	0.06±0.008	0.06±0.008	0.07±0.008	0.11±0.008	10±0.3	1.79±0.11
Test 6	0.06±0.003	0.06±0.006	0.06±0.006	0.18±0.02	0.10±0.0008	9.87±0.35
Tracer gas rate emission (10^{-4} m3/h)						
Test 1	4.6±0.07					
Test 2		3.42±0.07				
Test 3			4.95±0.07			
Test 4				12.41±0.18		
Test 5					6.17±0.09	
Test 6						8.77±0.12

Table 1: Tracer gas concentrations and source emission measured during the six tests.

The confidence intervals shown in Table 1 correspond to the standard deviations.

To describe the interzone air flows, we use both tracer gas mass conservation (equation I) and air mass conservation (equation II) in each zone:

$$\frac{V_i}{T_i}\frac{dC_{ik}}{dt} = \frac{S_{ik}}{T_i} + \sum_j \frac{(C_{jk} - C_{ik})}{Tj} q_{ij}(1 - \delta_{ij}) \qquad \text{(I)}$$

$$\frac{-V_i}{T_i^2}\frac{dT_i}{dt} = \sum_j \frac{q_{ij}(1 - \delta_{ij})}{T_j} - \sum_j \frac{q_{ji}(1 - \delta_{ji})}{T_i} \qquad \text{(II)}$$

We used two methods to solve these systems:

II.1 Global approach

In this approach, we consider the complete problem: there are as many tracer gases as zones. Here one test substitutes one tracer.

By writing the matrix form of the equation (I), we obtain under climatic conditions:

$$Q.C = S \qquad (III)$$

C_{ik} and S_{ik} represent the values of the k^{th} tracer (test) in the i^{th} zone .

The interpretation of air flow matrix (Q) requires a few explanation [7]: the diagonal elements q_{ii} represent the total air flow incoming or outgoing of zone i and coming from all the zones including outside. The non-diagonal elements represent air flows beetwen zones and should have a negative sign. Thus $-q_{ij}$ represents air flow from the zone j to the zone i. The air flow from the zone j to the zone i can be different from the flow from the zone i to the zone j. This matrix does not need to be symmetric .

For each zone i, we have also determined the infiltation flows q_{i0} by writing:

$$q_{ii} = \sum_{j=0}^{6} q_{ij} \qquad (IV)$$

$$q_{i0} = q_{ii} - \sum_{j=1}^{6} q_{ij} \qquad (V)$$

In the same way, the exfiltration flows q_{0i} is determined by writing:

$$q_{ii} = \sum_{j=0}^{6} q_{ji} \qquad (VI)$$

$$q_{oi} = q_{ii} - \sum_{j=1}^{6} q_{ji} \qquad (VII)$$

The total infiltration or exfiltration flows for the optibat cell is:

$$q_0 = \sum_{i=1}^{6} q_{i0} = \sum_{i=1}^{6} q_{0i} \qquad (VIII)$$

The second approach we have used to describe the same air flows is the disconnected approach. This approach consists in studiing each zone independently and determining all the flows . [4,8].

II.2 Disconnected approach

As shown in Figure 2, OPTIBAT cell is divided into 6 indoor zones and 1 outdoor zone, there are thus 42 interzone airflows which may theoretically exist.

Nevertheless we suppose that two non-adjacent zones do not exchange air directly without mixing in the intermediate zones [4].

Therefore, among the 42 air flows theoretically possible only 29 air flows do really exist.The other ones are equal to zero.

For each zone we use the conservation mass of each tracer (equation I). The matrix form of this sytem is:

$$C_i X_i = Y_i \qquad (IX)$$

where $$c_i(j,k) = \frac{c(j,k) - c(i,k)}{T_j} \qquad (i \neq j) \qquad \text{(X)}$$

To solve system (IX), we have used two methods:

The first one considers only the tests made in the adjacent zones of zone i. By inverting the square system extracted from the system (IX), we obtain the solution vector X_i

The second method considers all the six tests and using the mean square method, we also identify X_i. The results of this mean square method are in bold characters in Table 3

The results of these two approaches are reported in Tbles 2 and 3

j \ i	Outside	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Outside	130.5±3.3	46.4±6.3	33.75±1.8	48.6±1.8	2.28±12.1	-1.9±1.5	1.4±3.3
Zone 1	0.27±2.22	47.4±6.6	0.1±0.0	0.2±0.0	46.1±8.7	-2.0±0.8	-1.3±2.1
Zone 2	-1.2±1.2	0.3±0.0	34.5±1.9	0.4±0.0	36.10±3.7	2.36±0.4	-3.50±1.2
Zone 3	-5.6±2.2	0.2±0.0	0.2±0.0	50.0±1.9	42.8±4.7	16.1±1.2	-3.7±2.3
Zone 4	2.8±17.20	0.0±0.0	0.1±0.0	-0.2±0.0	129.3±14.0	43.9±3.9	82.1±16.9
Zone 5	45.9±4.0	0.2±0.0	0.2±0.0	0.3±0.0	0.3±0.0	62.3±4.3	15.3±1.6
Zone 6	88.4±11.7	0.3±0.0	0.2±0.0	0.3±0.0	1.53±0.1	-0.3±0.0	90.4±12.21

Table 2: Interzone air flows q_{ij} (m^3/h) calculated using global approach

j \ i	Outside	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Outside	140.1 **138.2**	46.6 **46.6**	33.75 **33.74**	48.8 **50.3**	**0**	18.2 **12.2**	-6.98 **-4.69**
Zone 1	0.5 **0.5**	47.4 **47.5**	0.1 **0.1**	**0**	46.9 **46.9**	**0**	**0**
Zone 2	-2.3 **-3.3**	0.34 **0.32**	34.5 **34.5**	0.4 **1.2**	36.9 **36.9**	**0**	**0**
Zone 3	6.3 **8.5**	**0**	0.2 **0.2**	49.9 **52.3**	43.6 **43.6**	**0**	**0**
Zone 4	**0**	0.5 **0.6**	0.4 **0.5**	0.7 **0.8**	129.2 **129.2**	44.0 **47.2**	82.2 **80.5**
Zone 5	46.5 43.8	**0**	**0**	**0**	0.3 **0.3**	62.2 58.5	15.3 **14.4**
Zone 6	89.1 89.6	**0**	**0**	**0**	1.53 **1.53**	-0.1 **-0.9**	90.5 **90.2**

Table 3: Interzone air flows q_{ij} (m^3/h) calculated using the disconnected approach. The values in bold characters are obtained using a mean square method.

The confidence intervals in these two tables are obtained by calculating the uncertainty about air flows rates:

III. ERROR ANALYSIS

Several methods are available for estimating the errors made in computing air flow rates. These methods are based on estimates of the precision of the measured tracer concentrations and source emission rates. The knowledge of the covariances of the measured data allows to compute the error about air flows rates. Each method depends on the numerical method used to identify the air flow rates.

III.1 Global approach

We have shown that:

$$Q.C=S \qquad \text{(XI)}$$

using the matrix indices explicitly:

$$q_{ij} = \sum_{k=1}^{6} S_{ik} C_{kj}^{-1} \qquad \text{(XII)}$$

The emission source rates and concentration are physically independent and, therefore their errors can be assumed to be uncorrelated.The formula for the variance becomes

$$\sigma_{q_{ij}}^2 = \sum_{p}^{6}\sum_{k}^{6}\left(\frac{\partial q_{ij}}{\partial S_{pk}}\right)^2 \sigma_{S_{pk}}^2 + \sum_{p}^{6}\sum_{k}^{6}\left(\frac{\partial q_{ij}}{\partial C_{pk}}\right)^2 \sigma_{C_{pk}}^2 \qquad \text{(XIII)}$$

Using equation (XII), we can show that:

$$\frac{\partial q_{ij}}{\partial S_{pk}} = \delta_{ip} C_{kj}^{-1} \qquad \text{(XIV)}$$

$$\frac{\partial q_{ij}}{\partial C_{pk}} = - q_{ip} C_{kj}^{-1} \qquad \text{(XV)}$$

The formula for the variance becomes:

$$\sigma_{q_{ij}}^2 = \sum_{p}^{6}\sum_{k}^{6}(\delta_{ip} C_{kj}^{-1})^2 \sigma_{S_{pk}}^2 + \sum_{p}^{6}\sum_{k}^{6}(q_{ip} C_{kj}^{-1})^2 \sigma_{C_{pk}}^2 \qquad \text{(XVI)}$$

In the same way, we calculate the variance of q_{i0}, q_{0i} and q_0 using their formulae.

The values of the uncertainties are reported in The tables 2.

IV CONCLUSIONS: Using OPTIBAT facility, it has been possible to use only one tracer gas injected at constant concentration to determine all the interzone air flow rates.

All the measurements have been done under the same steady climatic conditions The air flows have been computed for the complete problem which assumes that there are as many tracers as zones (one test substitutes one tracer) . We have also used the disconnected method by studiing all the zones independently.

For the complete problem, an error analysis enables us to give the uncertainties of air flows rates

These first results obtained by the two methods agree well. In order to complete the comparaison, we will carry out a more detailed error analysis using a pertubation method..

PERSPECTIVES: although the use of only one tracer gas allows us to describe all the interzone flows, we are now using three tracers gases to determine the same air flows under various climatic conditions.

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