IEA

International Energy Agency

INTERNATIONAL ENERGY AGENCY

ENERGY CONSERVATION IN BUILDING AND COMMUNITY SYSTEMS PROGRAMME
EXECUTIVE COMMITTEE MEETING
TECHNICAL DAY - SOPHIA ANTIPOLIS
2nd JUNE 1992

IEA ANNEX 23

MULTIZONE AIR FLOW AND POLLUTANT TRANSPORT MODELLING

CETHIL'S CONTRIBUTION TO ANNEX 23

F. ALLARD, P. DEPECKER, G. KRAUSS; F. AMARA, A. MEGRI
(INSA, France)

IEA - Energy Conservation in Buildings and in Community Systems

Annex 23
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June 2-4, 1992
Sophia Antipolis, France

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F. ALLARD, P. DEPECKER, G. KRAUSS, F. AMARA and A. MEGRI
Centre de Thermique de l'INSA Lyon, URA CNRS 1372
INSA Bât. 307 20, ave. Albert Einstein
F-69621 Villeurbanne Cedex
FRANCE

1. INTRODUCTION

CETHIL, Thermal Research Centre of the National Institute of Applied Sciences is a university laboratory associated to CNRS of 50 Staff scientists and Ph D students devoted to research in heat transfer.

Since 1982, our group has been developing various contributions to multizone air flow modelling (Roldan 1985, Cacavelli 1988). We contributed to the COMIS Project has a member, and more recently we have also been contributing to annex 20 with two projects: Large opening behaviour and zonal model development.

Few years ago we also developed a real scale experiment on a flat built called OPTIBAT (Allard et ali. 1987) in climatic controlled environment in order to get good quality data sets for building thermal model validation.

Taking into account our experience and projects, CETHIL's contribution to Annex 23 will focus on three main axes:

- ♦ COMIS development
- ♦ Full scale experiments
- ♦ Error propagation

2. COMIS DEVELOPMENT

As mentioned before, after various multizone thermal and airflow models developed in our group, we have been contributing to the COMIS project in 1988-1989 at LBL. In the first phase of Annex 23 we continue to work on COMIS by developing new algorithms and integrating new modules in the code.

More precisely we focus on HVAC network modelling and integration within the building solver and air quality evaluation in multizone configuration.

2.1. HVAC NETWORK MODELLING

First of all, during the last year, we developed a systematic modelling of each component of a ventilation network and their integration in COMIS.
16 different kind of elements including fans, ducts, junctions, flow controllers, dampers, ... have been identified, modelled and integrated to COMIS.

2.2. POLLUTANT TRANSPORT AND IAQ EVALUATION

Furthermore, a pollutant transport module already existed in COMIS (Rodriguez and Allard 1992), this module has been extended and coupled with an evaluation procedure of indoor air quality using the ventilation effectiveness concept in order to qualify the quality of ventilation in a multizone building.

Ventilation Effectiveness is a measure of how quickly an air-borne contaminant is removed from the room

$$\varepsilon^{c}=\frac{C_e(\infty)}{\langle C(\infty)\rangle}$$

with :
$C_e(\infty)$: contaminant concentration in exhaust air
$\langle C(\infty)\rangle$: room mean concentration of contaminant

$$C_e(\infty)=\frac{\sum_{i=1}^{i=Nz} F_{i0}C_i}{\sum_{i=1}^{i=Nz} F_{i0}}$$

$$\langle C(\infty)\rangle=\frac{\sum_{i=1}^{i=Nz} C_iV_i}{\sum_{i=1}^{i=Nz} V_i}$$

F_{ij} : air flow rate from zone i to zone j [m^3/s]
C_i : Contaminant concentration in zone i

V_i, V : room volume [m^3]

The Contaminant Removal Efficiency is derived from the ventilation effectiveness.

$$\eta^c = \frac{\varepsilon^c}{1+\varepsilon^c}$$

2.4 TEST CASE

The test building is a 5 zone single family house drawn on Figure 1.

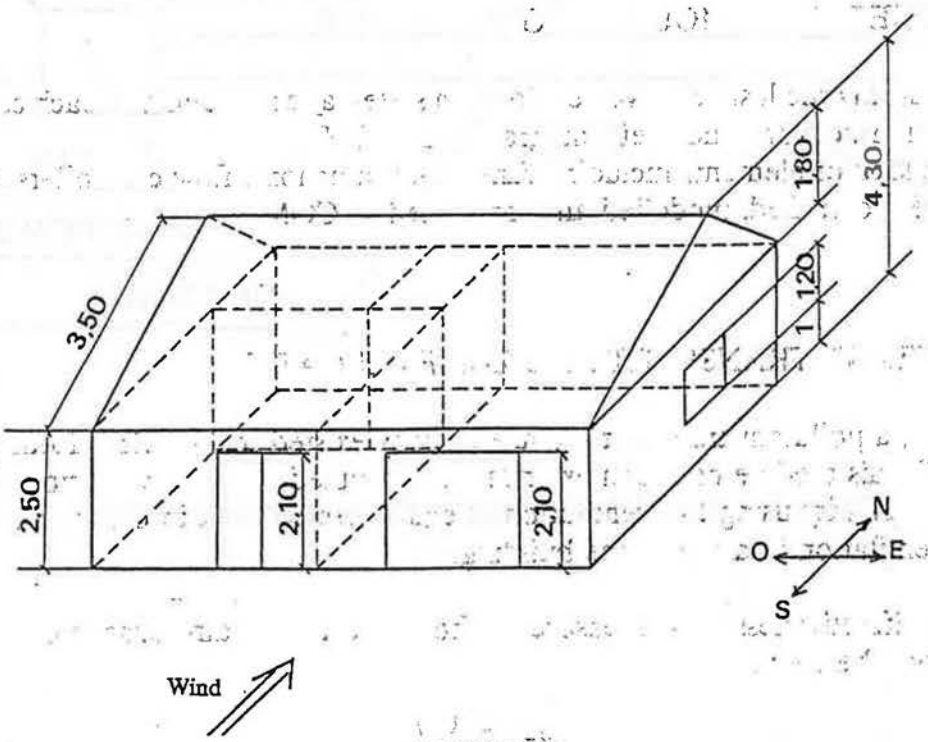

Figure 1: Test Case.

This building is characterized by 26 flow paths (doors, windows, cracks of internal and external walls...), 4 identical self-controlled air inlets located on living room walls and a mechanical exhaust system (fan, duct fittings, duct straights, such as elbow, diffuser, and flow controllers). Figure 2 gives a general scheme of this network.
Each component is described by its characteristic curves (see figures 3 to 5).
We consider in this example a typical winter day, with a south blowing wind.

Outdoor temperature: -2°C
Outdoor pressure: 101 300 Pa
Outdoor Relative Humidity: 60%
Indoor temperatures: Living room and Kitchen: 20°C
Bathroom: 22 °C
Toilets: 19°C
Attic: 10°C
Indoor Relative humidity: 50%

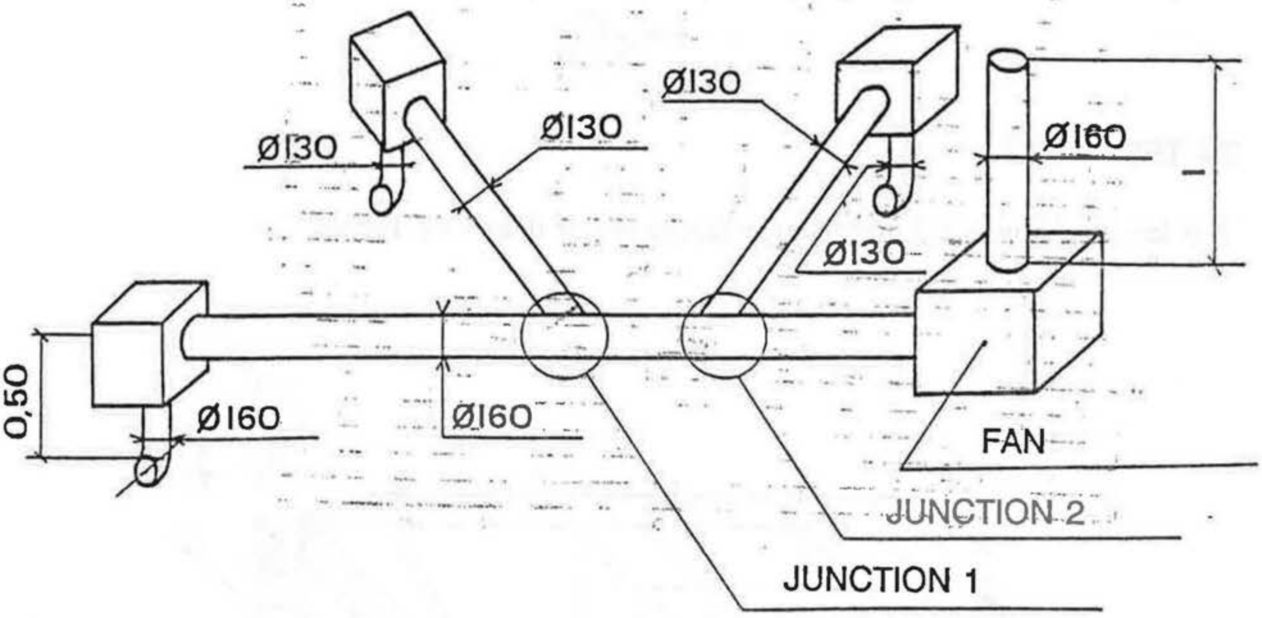

Figure 2: General description of the ventilation network.

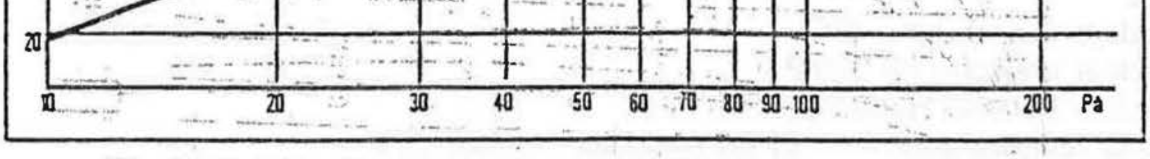

Figure 3: Characteristic curve of the air inlets.

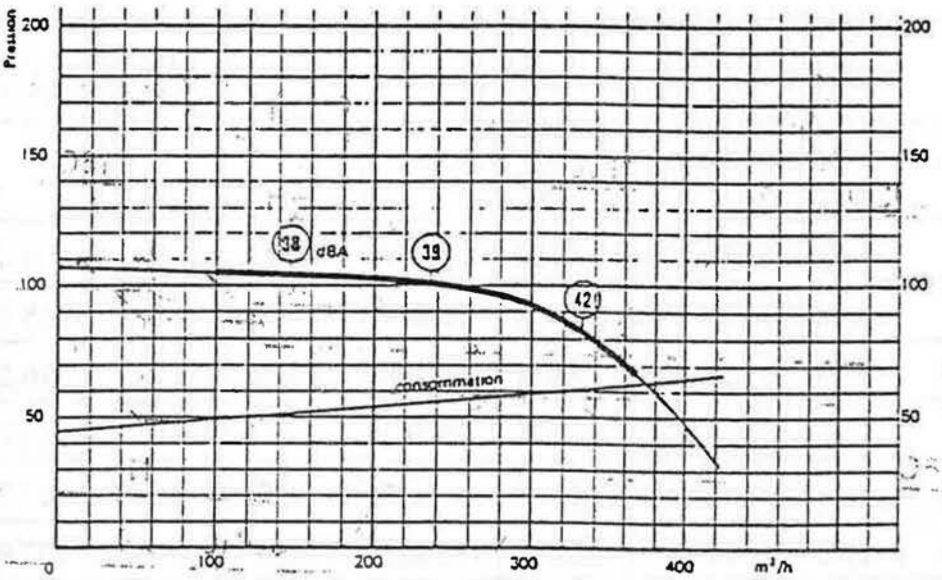

Figure 4: Characteristic curve of the fan.

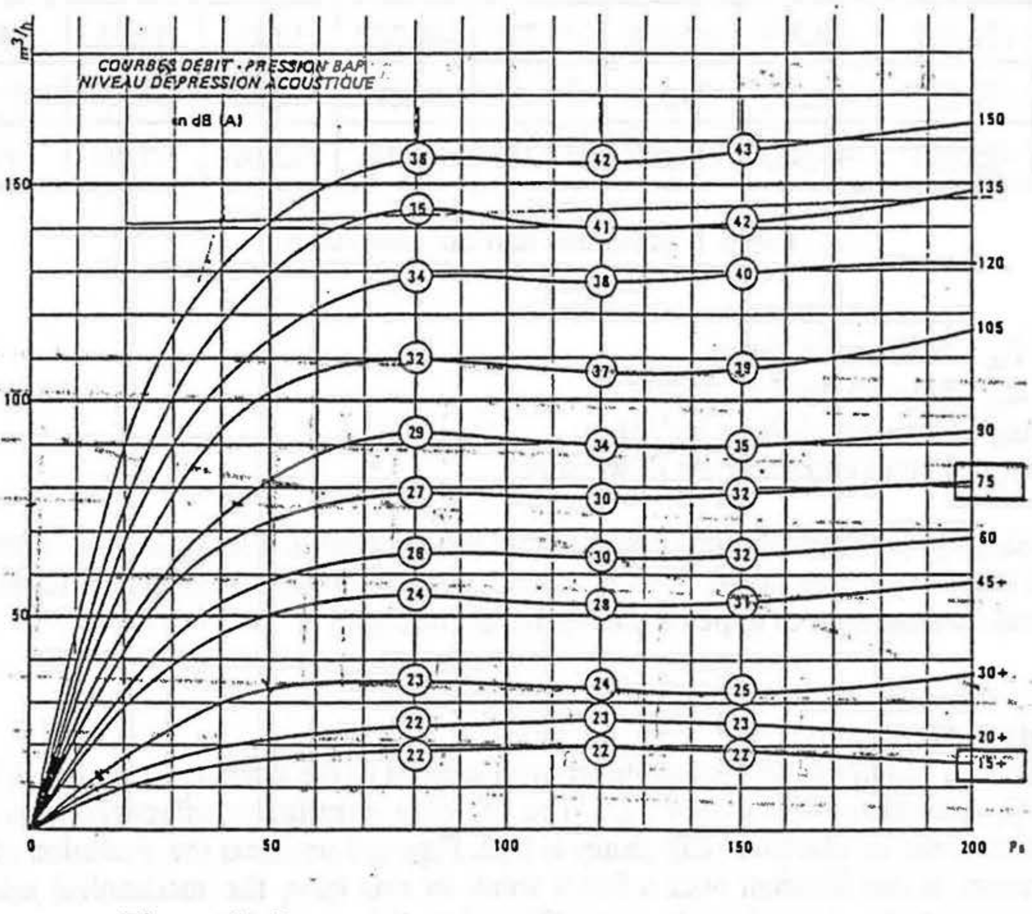

Figure 5: Characteristic curve of the exhaust grids.

2.4.1. Wind Speed Influence:

At first we vary the wind speed from 0 to 12 m/s. Table 1 gives the results obtained.

V_W [m/s]	P [Pa]					m_A [m^3/h]	m_B [m^3/h]	m_C [m^3/h]
	Kitchen	Living -room	Toilets	Bath room	Attic			
0	-31.19	-4.83	-33.254	-33.352	-34.899	115.2	0	115.2
1	-31.481	-4.98	-33.551	-33.650	-35.274	115.56	0	115.56
2	-32.485	-5.631	-34.574	-34.674	-36.479	116.28	0	116.28
3	-34.665	-7.48	-36.774	-36.875	-38.762	117	0	117
5	-43.918	-16.823	-46.048	-46.147	-47.222	117.72	0	117.72
6	-49.788	-22.601	-51.941	-52.041	-52.821	118.08	9.73	127.81
7	-55.343	-27.731	-57.555	-57.656	-58.830	118.8	22.60	141.4
8	-60.726	-32.254	-63.024	-63.131	-65.440	119.52	33.72	153.24
9	-66.084	-36.431	-68.470	-68.583	-72.525	120.6	43.90	164.5
10	-71.214	-40.277	-73.599	-73.723	-80.332	120.6	53.83	174.43
11	-77.173	-44.371	-79.557	-79.695	-89.292	120.6	66.63	187.23
12	-85.832	-49.833	-88.208	-88.365	-98.986	120.6	77.10	197.7

Table 1: pressures and air flow rates.

Where:

- V_W : wind speed [m/s]
- m_A : Exhaust air flow [m^3/h]
- m_B : Crossing air flow [m^3/h]
- m_C : Total ventilation air flow [m^3/h]

The crossing air flow is zero until 6 m/s. After this threshold, it continuously increases the total ventilation rate up to 64% at 12 m/s. The concept of protection level of a mechanical exhaust system appears clearly in this example.

2.4.2. Indoor Air Quality:

We consider in this illustrative example an oven located in the kitchen. Its power is 3 kW and its CO_2 emissive power is 0.0981 g/s. The resulting Ventilation Effectiveness is 4.64, and the Contaminant Removal Efficiency is 0.82. Figure 6 presents the evolution of $C0_2$ concentration in the Kitchen with a 2m/s wind. In this case, the mechanical exhaust system appears to be a good solution, no $C0_2$ is found in the living room.

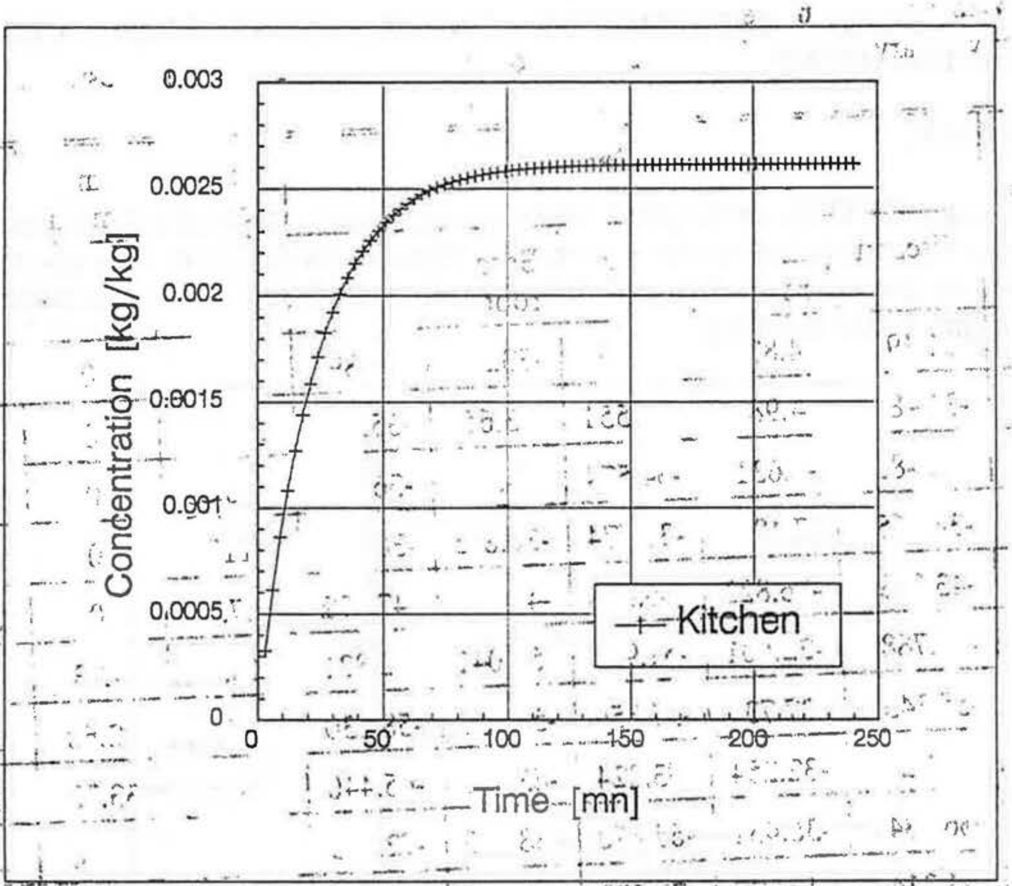

Figure 6: Evolution in time of CO_2 concentration in the kitchen.

2.5. TIME SCHEDULE:

These works, integrated in Subtask I (model development) will be available for all participants in a next COMIS version proposed for our fall meeting in Budapest.

After an evaluation of the code, it will be then possible to integrate new algorithms, (large openings, new ventilation systems) and preliminary results of the complete code integrating the user interface are planned for 1993.

The final product including the user interface should be available in March 1994.

2.6. EXPECTED RESULTS:

The first expected results of this task are a new version of the code, new algorithms and modules and their technical reports. Nevertheless, we expect also a contribution to the sensibility analysis.

3. FULL SCALE EXPERIMENTS UNDER CONTROLLED CLIMATIC ENVIRONMENT

3.1. OPTIBAT:

Few years ago, CETHIL developed a real scale experiment made of a 88 m^2 apartment built in our laboratory hall under a controlled climatic environment. This apartment is configured as presented in Figure 7. It has been divided into zones representing the various rooms of the dwelling.

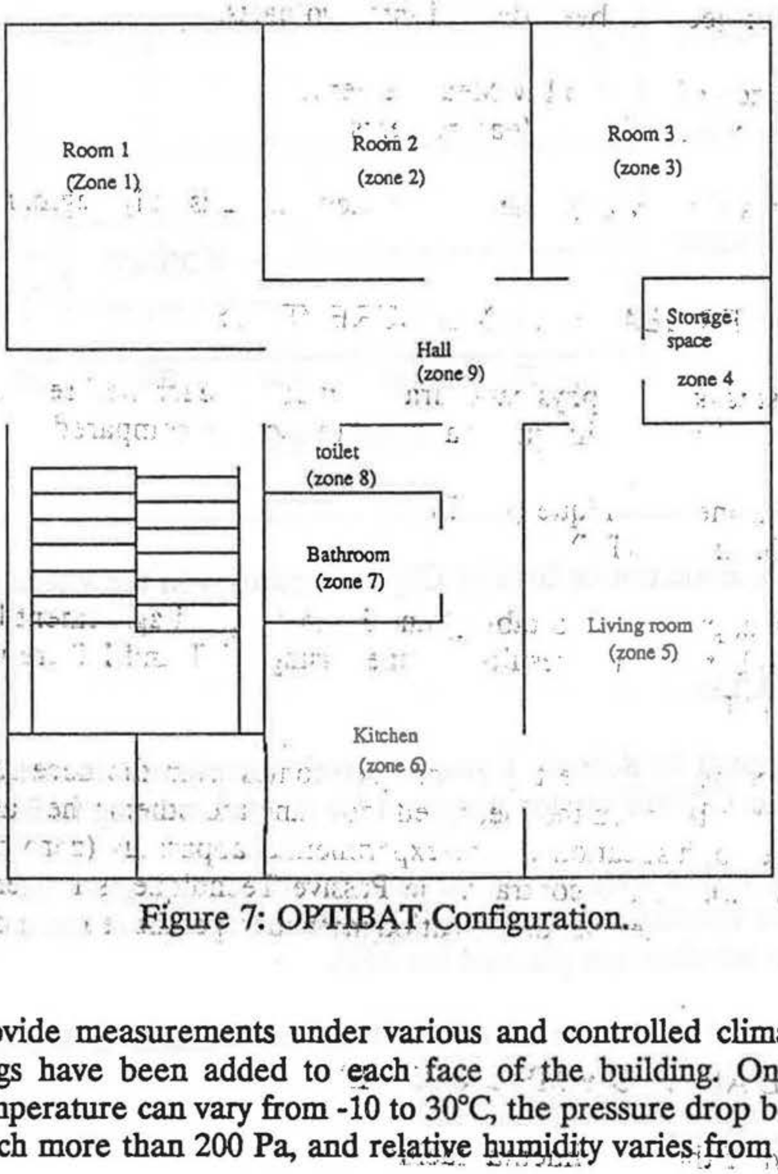

Figure 7: OPTIBAT Configuration.

In order to provide measurements under various and controlled climatic conditions, climatic housings have been added to each face of the building. On the two main facades, air temperature can vary from -10 to 30°C, the pressure drop between the two facades can reach more than 200 Pa, and relative humidity varies from 30 to 80%.

The four other faces of the dwelling are controlled by a special housing simulating adjacent apartments, and temperature and pressure drop are controlled independently.

3.2. THE EXPERIMENTAL FACILITY

OPTIBAT facility had been devoted until now to the validation of numerical codes of thermal behaviour of buildings developed by CETHIL without specific measurements of multizone air flows. In a first phase of our program, this facility had to be modified in order to provide a reference experimental tool for multizone airflow measurement techniques and experimental data sets available for numerical code validation within the frame of annex 23.

This experimental project has been divided into two parts:

Part 1: Interzone Permeability Measurements
Part 2: Interzone Air Flow Measurements

Until now Part 1 has already been carried out, and Part 2 is only beginning.

3.3. INTERZONE PERMEABILITY MEASUREMENTS:

The aim of this first task is the physical characterization of each wall regarding to its air permeability. Two different techniques have been used and compared:

- ♦ Guarded Zone Technique (GZT)
- ♦ Passive Technique (PT)

The results obtained, presented in table 2 and 3 show a good agreement between both techniques, the gap between the results obtained using GZT and PT are usually within the confidence interval of the results.

The main difference between the two techniques comes from the necessary control of the zero pressure drop between the measured room and the others when using the GZT which means more sophistication in the experimental apparatus (zero pressure drop control, extra fans, ...). At the contrary, the Passive Technique is longer in time and needs a more powerful numerical identification method to get the leakage characteristics K and n.

3.4. MULTIZONE AIR FLOW MEASUREMENTS

3.4.1. Modification of the experimental facility

Before developing the second phase of our project, we had to modify our experimental facility in order to improve its quality with regard to tracer gas technique measurements. In order to save energy, the whole thermal conditioning of OPTIBAT had been designed with closed loops. This design is no more suitable for tracer gas measurement because it will increase strongly the noise on the measurements due to the tracer gas recirculation.

	Guarded zone method		Passive method	
designation	n (Flow exponent)	K(m3/h.under 1Pa) (Permeability coef)	n	K
Paroi W12	Tighted wall			
Paroi W13	Tighted wall			
Paroi W14	0.59±0.03	12.62±1.04	0.58±0.02	13.43±0.91
Paroi W23	0.57±0.02	13,93±0.84	0.60±0.04	11.82±1.4
Paroi W33	0.61±0.03	9.37±1.15	0.55±0.04	10.02±1.08
Paroi W34	Tighted wall			
Paroi W43	Tighted wall			
Paroi W52	Tighted wall			
Paroi W53	0.55±0.03	13.52±1.6	0.57±0.01	13.34±0.21
Paroi W63	0.52±0.05	6.79±1.15	0.56±0.005	5.86±0.02
Paroi W73	Tighted wall			
Paroi W83	0.65±0.05	3.34±0.59	0.59±0.04	3.94±0.54

Table 2: Leakage characteristics of outdoor components.

	Guarded zone method		Passive method	
Désignation	n (Flow exponent)	K(m3/h under 1Pa) (Perleability coef)	n	K
Paroi W11=W22	0.95±0.05	0.01±0.02	0.90±0.001	0.14±0.001
Paroi W21	0.71±0.01	19.30±0.38	0.78±0.05	20.22±1.03
Paroi W22	0.95±0.05	0.01±0.02	0.90±0.001	0.14±0.001
Paroi W24	0.99±0.01	0.08±0.02	0.87±0.01	0.17±0.01
Paroi W31	0.66±0.001	14.17±0.03	0.59±0.004	14.94±1.26
Paroi W32=W24	0.99±0.01	0.08±0.02	0.87±0.01	0.17±0.01
Paroi W41	0.92±0.03	2.54±0.22	0.84±0.02	2.49±0.16
Paroi W42	0.66±0.01	2.89±0.21	0.65±0.01	2.97±0.08
Paroi W44	0.51±0.002	5.48±0.04	0.51±0.01	5.64±0.02
Paroi W51	0.71±0.03	14.67±1.54	0.76±0.01	15.03±0.64
Paroi W54=W62	0.64±0.01	6.47±0.02	0.64±0.001	6.29±0.02
Paroi W61=W72	0.74±0.05	1.76±0.26	0.81±0.02	1.24±0.21
ParoiW64	0.77±0.02	1.64±0.06	0.69±0.06	1.99±0.27
Paroi W71	0.89±0.04	4.59±0.999	0.80±0.02	4.83±0.31
Paroi W72	0.74±0.05	1.76±0.26	0.81±0.02	1.24±0.21
Paroi W74	0.97±0.01	0.34±0.01	0.97±0.01	0.34±0.01
Paroi W81	N.D	N.D	N.D	N.D
Paroi W82=W74	0.97±0.01	0.34±0.01	0.97±0.01	0.34±0.01
Paroi W84	N.D	N.D	N.D	N.D

N.D: undetermined coefficients

Table 3: Leakage Characteristics of Indoor Components.

In order to avoid this problem, a new design has been made, the whole conditioning system is now working in open loops injecting outdoor fresh air taken on one side of our hall and rejecting exhaust air on the other side. Figure 8 describes these principles.

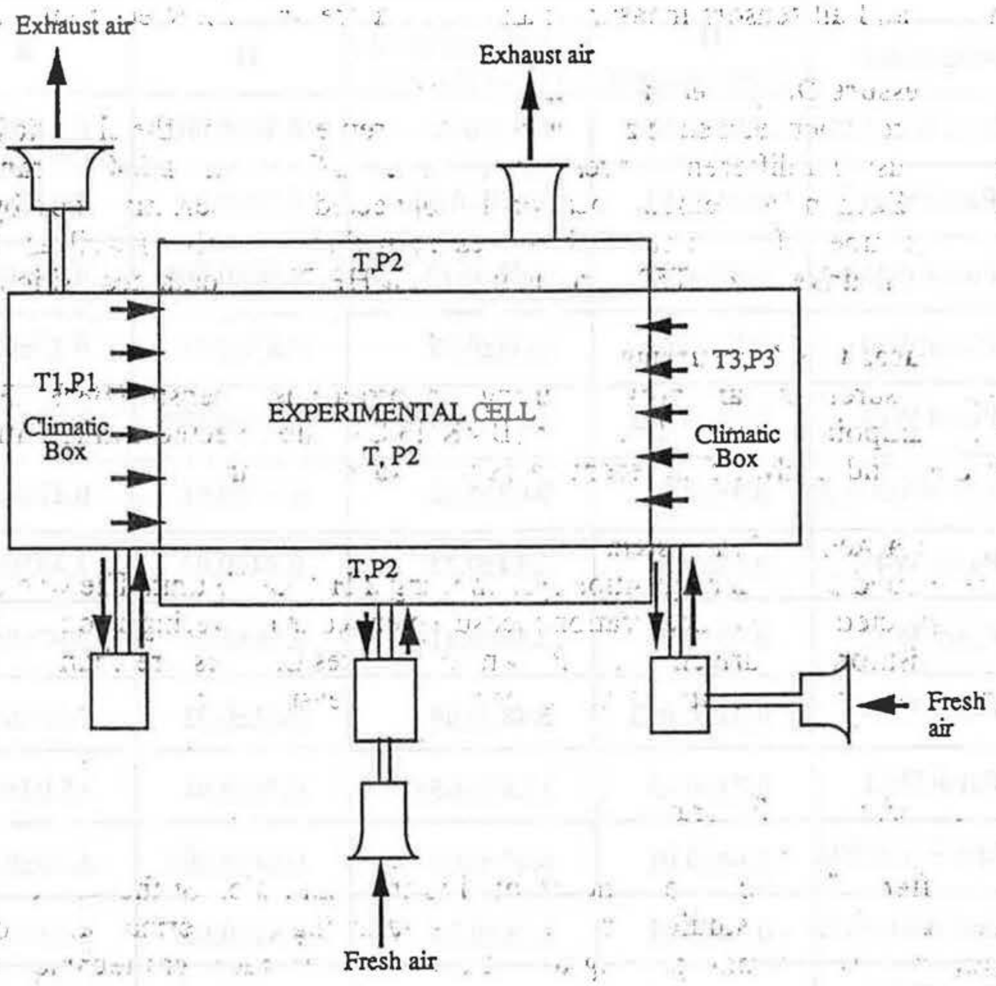

Figure 8: Climatic environment of OPTIBAT.

3.4.2. Measurement facility

In order to get complete experimental data sets, air temperature, pressure drop and tracer gas concentration have to be measured in each room and in each climatic housing bounding the dwelling cell. Obviously the number of sensors is limited and we defined on one hand a minimum requirement for each room and on the other hand the possibility of specific studies with a higher density of sensors in one room which introduces a flexibility criterion in designing the measurement device.

The minimum requirement is one air temperature, one pressure and one concentration measurements in each zone of the dwelling and in each climatic housing. The location of the sensors being at the centre of the zone. Nevertheless, for specific studies on concentration homogeneity in one zone, thermal stratification ..., more sensors will be necessary. This design leads us to a total amount of 40 temperature sensors, 20 sampling location for concentration and the same number of pressure measurements.

Temperature Measurements:
We use 40 RTD 100 Ohm sensors calibrated in our laboratory and distributed in the various zones of the apartment. The final accuracy resulting of the calibration is better than .1°C and all sensors measuring air temperature are protected from wall radiation.

Pressure Drop Measurements:
Pressure drops between each zone and outdoor represented by the climatic housings are measured using a differential pressure transducer FC040 with a 200 Pa range and 1 Pa accuracy. Each measurement location is connected to a selection box by horizontal pneumatic tubes. This selection box located within the cell as well as the pressure transducer is driven by a T5200 computer via a HP 7500B data acquisition system.

Tracer Gas Measurements:
These measurements are provided using a photo acoustic sensor (B&K 1302) coupled with a multipoint doser and sampler (B&K 1303). The selected configuration enables us to dose and analyze 5 different gases plus water vapour.

Data Acquisition System:
We developed our own acquisition system using a HP 3500B unit. The whole system has been connected to the concentration measurement code delivering a complete integrated data acquisition tool driven by the PC which manages the pressure channel selector, and all the pressure, temperature and concentration measurements.

3.4.3. Experimental Program

After a first period of time devoted to the calibration of the whole experimental facility and specific studies on tracer gas sampling or thermal and concentration stratification, we are now planing to test two different tracer gas techniques:

- ♦ Monogas Multizone Technique
- ♦ Multigas Multizone Technique

Monogas Multizone Technique
We use only one tracer gas injected at a constant concentration level in one zone, and we measure the resulting concentrations in all the zones under fixed climatic conditions. Repeating this process for different concentration levels and for each zone, delivers the 90 interzonal air flows of the problem. As we are able to maintain constant climatic conditions during the whole experiment, this first method can work with a good accuracy even if it is time consuming.

Monogas Multizone Technique
In order to reduce the total period of the experiment, the method to be used is a multigas technique. Nevertheless, in real applications, it is not possible usually to use a number of gases equal to the number of zones. That is the reason why we decided to use three different gases only.

3.5. TIME SCHEDULE:

The interzone permeability measurements have already been performed, they have to be completed and reported to Annex 23. The OPTIBAT experimental facility has been retrofited this winter and the multizone air flow experimental facility is already installed. We are presently working on specific experiments on tracer gas injection, calibrating the concentration control system and planning the whole experimental procedure. First results with the monogas technique should be available this fall and a first report will be presented to the next Annex 23 meeting in september.

3.6. EXPECTED RESULTS

The main expected result of this second project is obviously on the one hand a complete data set for multizone air flow model evaluation and on the other hand a well known reference experimental tool for testing different techniques or equipments for multizone permeability and/or multizone air flow measurements.

The main advantage of laboratory experiments under controlled environment is the quality of the boundary conditions, the possibility of parametric studies, the reproducibility of the experiments, and the possibility to generate steady states or transient regimes between two steady states which offers a wide opportunity when evaluating numerical models.

4. ERROR PROPAGATION AND MODEL EVALUATION

The last project related to Annex 23 deals with the general problem of error propagation and more generally speaking the evaluation of numerical or experimental model reliability.

When elaborating a theoretical model, a physicist uses a conjunction of elementary mathematical tools leading to a representation (model) of the physics reality. Most of the time, this model is built by using elementary models of single phenomena containing experimental knowledge contained in experimental data measured by the physicist. At the end the complete model can reach a very high complexity and it becomes very hard to define the quality of the answer. Usually, the model is described by a set of non linear algebraic and integro-differential equations and their boundary conditions and to predict the behavior of the physical system can be reduced to the solution of the numerical system delivering the state variables defining the local thermodynamical equilibrium of each elementary component.

In this very usual way to represent the physical reality, the main issue is in fact to define the validity domain of the results. Unfortunately, this physical requirement is very often forgotten and building physics is not a singular case.

When planning the tasks to be realized in Annex 23, a special care has been made on experimental validation. In fact the evaluation of a code is a comparison between to models of the reality, the first one given by experiments with a limited number of sensors in specific locations with a specific accuracy and the second one given by a numerical model built from a physical model with restrictive hypotheses. Furthermore, in the experimental model, all physical quantities are not directly measured, but they can be identified by a numerical algorithm.

The first step in the way of evaluating a model is then to define the distance between both realities. The sensibility analysis proposed by J.M. Fürbringer is the first step in obtaining this information. The main problem here in this kind of statistical approach is that it is time consuming and it can become very heavy in case of a complex system of nonlinear equations.

Few years ago mathematicians (Gauthier et ali. 1986) have demonstrated that in some cases it was possible to reduce tremendously the calculation time by using new procedures of identification of a upper limit of uncertainty.

We are presently working on basic research about this new concept of error propagation evaluation. Until now it is too early to say if it will be applicable to multizone air flow modelling. If we succeed, we think it will be a very powerful way, but if we are not able to develop this tool within the frame of Annex 23, we will use the usual approach already proposed.

5. CONCLUSION

CETHIL's contribution to Annex 23 is clearly divided in three different tasks corresponding for us to specific studies.

First of all we will continue to develop COMIS by integrating more physical knowledge within the code and then we will begin a sensitive analysis of tool.

In parallel with this numerical task, we are developing a reference experiment in climatic controlled environment.

Finally, we are presently developing new mathematical tools to study error propagation in non linear system of equations. Our goal is to incorporate this work in the evaluation phase of the code.

These works are included in a general project on multizone air flow modelling and measurement and indoor air quality prediction we are developing in parallel.

Acknowledgements

The experimental project OPTIBAT has been supported by Région Rhône Alpes and ADEME regional centre in Lyon. (Délégation Régionale de l'Agence de l'Environement et de la Maîtrise de l'Energie)

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