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MODELING AND PREDICTING OF POLLUTANT TRANSFER IN MULTIZONE BUILDINGS COUPLED WITH VENTILATION NETWORKS.

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Air flow modeling and contaminant dispersion in multizone buildings is still a hard task which has motived the COMIS and then annex 23 projects.

During the last two years, CETHIL has contributed to these joint projects by developing the COMIS code in order to predict on the one hand the coupled behavior of multizone buildings equiped of their complete ventilation network and on the other hand the resulting transfer of contaminants.

In a first step we present here some results obtained in simulating a multizone building coupled with a ventilation network.

In a second step, an air quality index for multizone buildings is proposed. By coupling the ventilation code with a pollutant transfer model, we are then able to predict and qualify the ventilation efficiency of a multizone building coupled with a ventilation network.

1.- Introduction :

A literature review shows that the actual trends to prediction of air flow in multizone buildings are not only due to economical reasons but mainly to indoor air quality, acoustical and thermal comfort improvements.

During the last decade, almost fifty models have been developed in eight countries [1]-[4]. Except some models the analysis of interaction between HVAC systems and building infiltration is seldom studied [5].

In this paper our first objective is the study of a building coupled with HVAC systems, in order to find out some complex phenomena resulting from coupling the building with its ventilation network.

Our second objective is to qualify the ventilation efficiency of a multizone building coupled with a ventilation network by an air quality index, and to provide guidance to occupations on ways to reduce their exposure to pollutants.

2.- Modeling principles :

We use COMIS model as a support [4]. In COMIS, the building and HVAC systems are represented by nodes connected by different kind of links (cracks, fans, ducts, large openings, etc); every node represents a zone at thermodynamical equilibrium and represented by its state variables (temperature and reference pressure).

The building and the HVAC systems are coupled by using simple laws between flow and pressure. For different components (cracks,fans,etc), these relationships are based on the same physical principle.

In order to identify the law between flow and pressure, three steps are necessary:

- calculate the coefficient of these laws,
- calculate the pressure difference through each component, using Bernoulli equations,
- correct these relationships, according to the real conditions.

3.- Component Modeling :

3.1.- Ducts and Duct Fittings :

We consider two types of ducts :

- Straight ducts characterized by their dimensions and a friction factor.
- Duct fittings characterized by their type, their geometry and a local loss coefficient.

In order to integrate ducts and duct fittings into the general network, their behavior is represented by power law functions (orifice laws).

$$Q=C(\Delta P)^{N}$$

C and N are identified by simulating at first the behavior of the duct for various flow regimes, using its characteristic friction factor (for ducts) or local loss coefficient (for duct fittings) to calculate the pressure loss [6]-[8].

The results can be drawn as a flow function and C and N are obtained by numerical regression.

Then the flow in the duct is corrected as a function of the real thermophysical characteristics in each duct.

3.2.- The junction of a Tee :

The junction is represented by three pressure nodes and treated as a particular pressure node by COMIS. It means that the static pressure of the node with the big flow is iteratively calculated by the solver. With this pressure and using the relation of pressure loss, we deduce the other two pressures. Figure 1 represents one case of the six cases existing (Table 1)

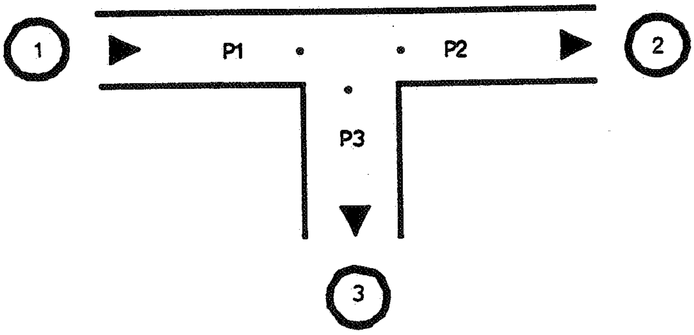
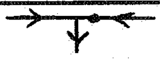


Figure 1 : Pressures at a Junction of a Tee

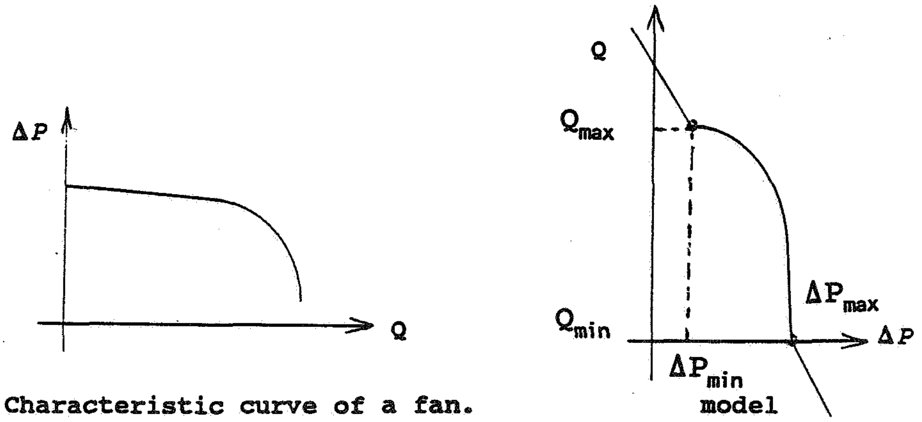
Table 1 : Different configurations of a Tee Junction.

Configuration	Diagram
T splitting	
T gathering	
straight stream gathering	
lateral stream gathering	
straight stream splitting	
lateral stream splitting	

3.3.- Fans :

Fan is modeled via a polynomial function for every rotating speed. In our model, we use the polynomial ($Q = f(\Delta P)$) instead of ($\Delta P = f(Q)$) given experimentally or by the constructer. Out of the definite range [ΔP_{min}, ΔP_{max}], we assume a linear behavior of the fan; this curve passes through the two points (ΔP_{min}, Q_{max})and (ΔP_{max}, Q_{min}).

This characteristic curve is then corrected if we consider the effect of density and rotating speed. Figure 2 gives an example of fan model.



Characteristic curve of a fan.

model

Figure 2 : Fan model.

3.4.- Flow controllers :

Flow controllers represent most of the available dampers or regulators used in a ventilation network. The basic premise of flow controllers is that they have a flap or valve which may throttle the flow by gradually closing the opening when the pressure increases.

A flow controller is called ideal if after a first pressure threashold it delivers a constant flow rate when the pressure increases.

Furthermore, a flow controller is called symmetrical if it has exactly the same behavior for both positive and negative pressure drops.

Figures 3 presents the 4 combinations we can find between this two definitions.

F1 : Symmetrical ideal flow controllers.
F2 : Non symmetrical ideal flow controllers.
F3 : Symmetrical non ideal flow controllers.
F4 : Non symmetrical non ideal flow controllers.

For each category we can represent the behavior of any flow controller by power law functions (range 1+ and 1-) and polynomial laws (range 2+, 2- and 3+, 3-).

In the case of self-controlled air inlets, the aim is to limit the crossing air flow in the building. This phenomenon of crossing air flow becomes more important in a building with a double exposition and a high wind velocity [9].

One application of the self-controlled air inlets is to automatically control the ventilation as a function of the concentration of differents zones. If the concentration is less than the peak, the damper is closed, the air is exhausted by a fixed orifice.

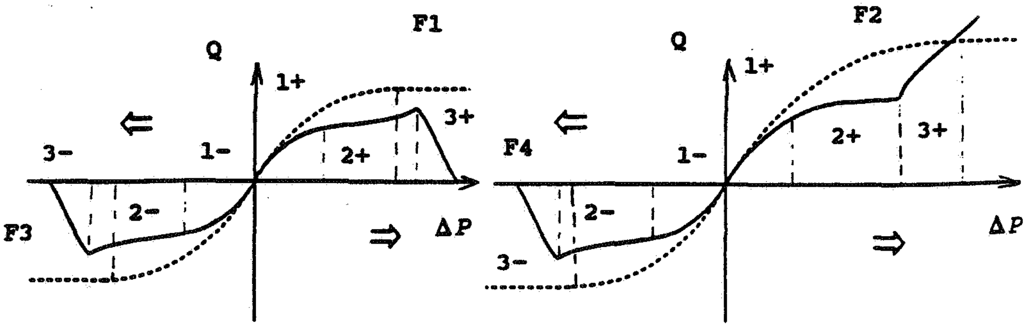


Figure 3 : Characteristic curves of flow controllers.

4.- Pollutant transport and IAQ evaluation :

Furthermore, a pollutant transport module already existed in COMIS [10], 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 [11]-[13].

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 at time ∞

$\langle C(\infty) \rangle$: room mean concentration of contaminant

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

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

F_{i0} : air flow rate from zone i through the exhaust duct to outside [m^3/s].

C_i : Contaminant concentration in zone i.
V_i : Room volume [m^3]

The Contaminant Removal Efficiency is derived from the ventilation effectiveness.

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

We define the instantaneous exposure, E, to a pollutant at time t as the concentration, C(t), in the zone with the person at time t :

$$E=C(t)$$

The cumulative exposure from t_1 to t_2 is given by :

$$E_C=\int_{t1}^{t2} C(t)\,dt$$

E_C may be obtained by numerical integration of the calculated contaminant concentration curve.

5.- Test case :

The test building is a five zone single family house presented in Figure 4.

This building is characterized by 26 flow paths (doors, windows, cracks of internal and external walls...), 4 identical self-controllled 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 5 gives a general scheme of this network. Each component is described by its characteristic curves (see figures 6 to 8).
We consider in this example a typical winter day, with a south blowing wind.
Outdoor temperature : -2°C
Outdoor pressure : 101300 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%
The Cp-values used for the calculation are given in Table 1.

Table 2 : Cp-Values for each wall

South façade	West and East façades	North façade	South roof	North roof	End of exhaust duct
+ 0.25	- 0.70	- 0.50	- 0.55	- 0.60	- 0.75

5.1.- Wind Speed Influence :

We vary the wind speed from 0 to 12 m/s; according to the wind velocity, the building ventilation works as explained next:

- At zero wind velocity, the air goes through the two façades (windward and upwind façades). The air change rate is equal to the specific flow of ventilation (i.e. the flow is controlled by the fan).

- At a low wind velocity, the air still goes through the two façades with an increased flow at the windward and a decreased flow at the upwind façade. The total air change rate is identical.

- At a given wind velocity (6 m/s in our case), named the protection level, the air flows through the windward façade. The total air change rate is higher than previously. A flow going through the windward facade, which is a function of the façade infiltration and the wind velocity, is added to the specific flow (flow of the fan). The crossing air flow is zero up to the protection level. After this threshold, it continuously increases the total ventilation rate up to 64 % at 12 m/s (Figure 9).

5.2.- Indoor Air Quality :

At first we consider an oven located in the kitchen (its power is 3 kW and its CO_2 emissive power is 0.0981g/s) and a CO_2 source pollutant in the living room (its CO_2 emissive power is 0.01g/s, which is equivalent to two person emission). The resulting Ventilation Effectiveness is 2.75, and the Contaminant Removal Efficiency is 0.73. Figure 10 presents the evolution of CO_2 concentration in different rooms with a 1 m/s wind. In this case, the mechanical exhaust system appears to be a good solution, the concentration in the living room is lower.

Secondly, we consider two persons, with different activity patterns, and we calculate the exposure of every one to different sources of CO_2 pollutants. The first person is in the kitchen during 10 minutes, moves to the outdoor during 4 hours and 40 minutes (we suppose that the outdoor concentration is zero), then prepares the lunch in the kitchen for 1 hour, after goes outdoor for 4 hours, returns in the kitchen during 10 minutes, then leaves the building for 1 hour and 50 minutes, prepares the dinner for 1 hour and finally he stays in the living room. The second person stays in the living room during 24 hours. The instantaneous and cumulative exposures (during one day) to the pollutant CO_2 for the two persons seperatly are given in figures 11 and 12. We notice that, while the instantaneous exposure for the first person is some times (initial instantaneous exposure and when he uses the kitchen) much higher than for the second person, the cumulative exposure for the first person is very low.

6.- Conclusion :

The actual version of COMIS code may be used as the core of a design tool of a multizone building and enables diagnosis of its defective ventilation network. An interface allowing pre and post processing of data and results is esssential to use such a code in a research organization.

The case study presented in this paper is only given as an illustrative example, it demonstrates the feasability of our project developed within the frame of an international effort coordinated by the International Energy Agency, Annex 23.

This is only the first step of the study and characterization of a building from the air quality point of view. In order to enable a real air management introduction of new components which pollution level is dealing with their behavior with time is now necessary.

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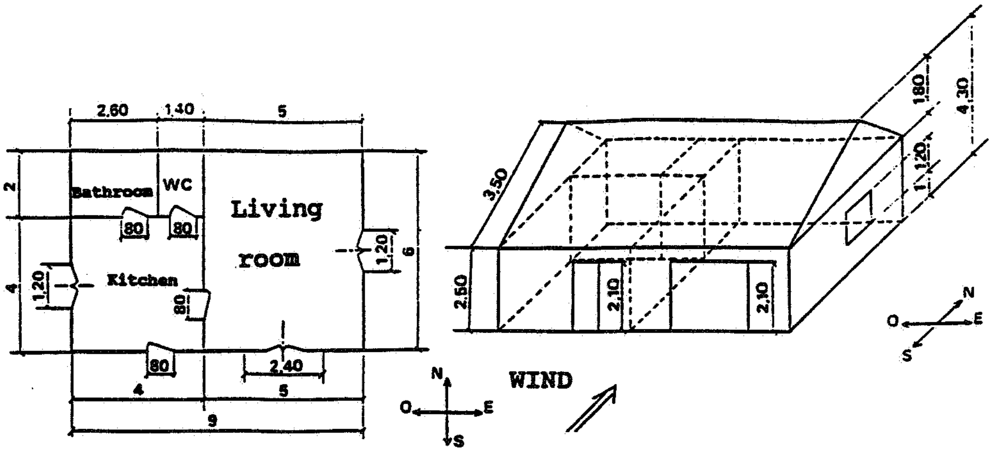

Figure 4 : Test Case.

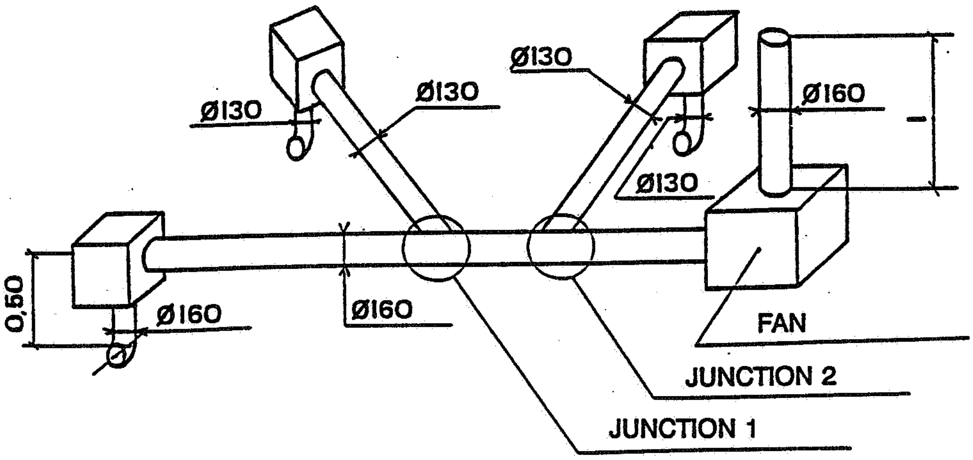

Figure 5 : General description of the ventilation network.

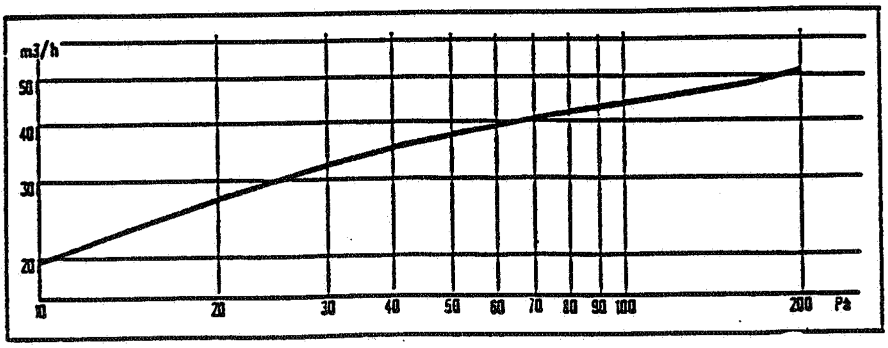

Figure 6 : Characteristic curve of the air inlets.

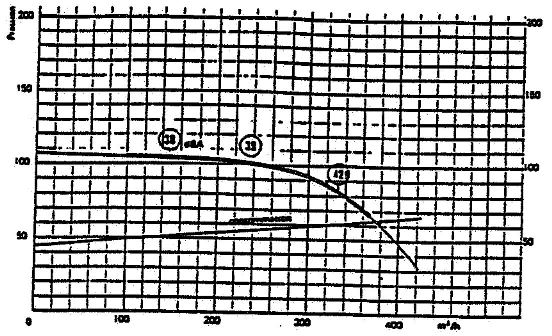

Figure 7 : Characateristic curve of the fan.

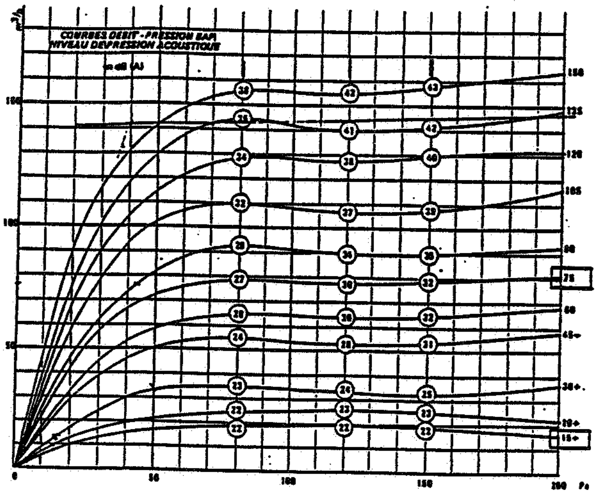

Figure 8 : Characteristic curve of the exhaust grids.

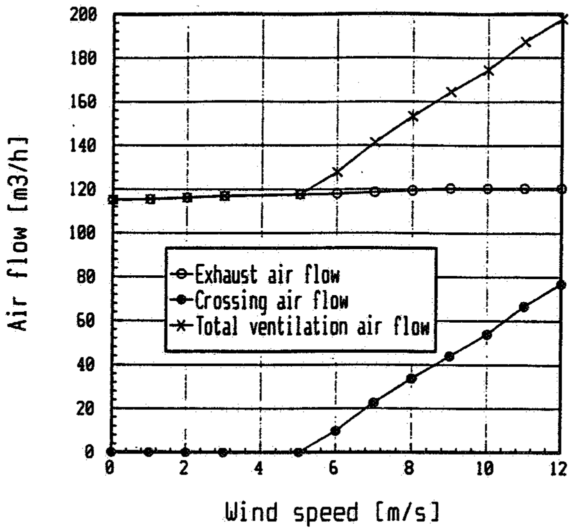

Figure 9 : Wind Speed Influence.

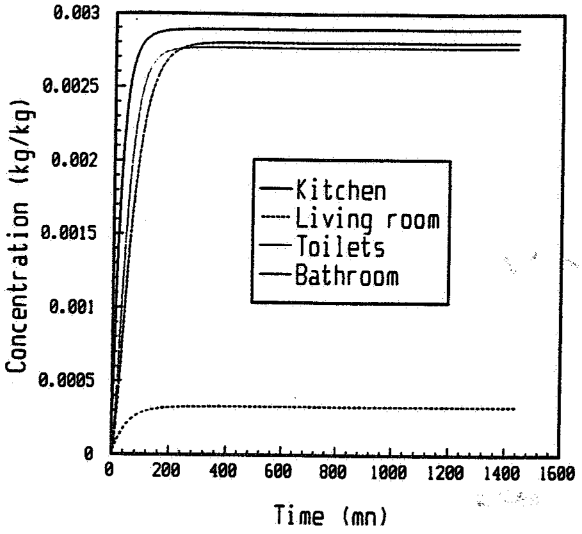

Figure 10 : Evolution in time of CO_2 concentration in different rooms.

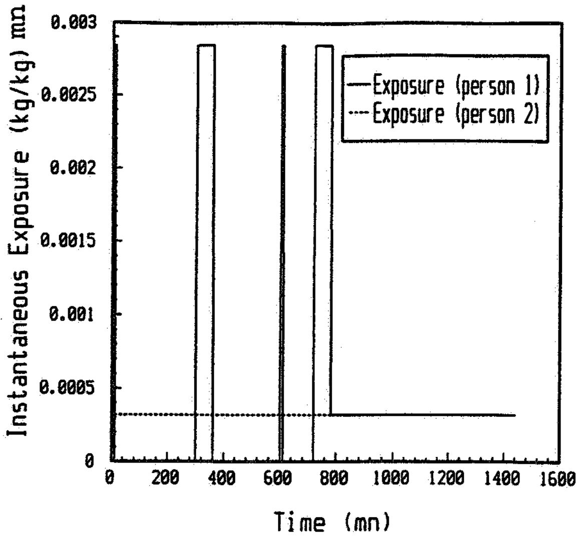

Figure 11 : Instantaneous exposure.

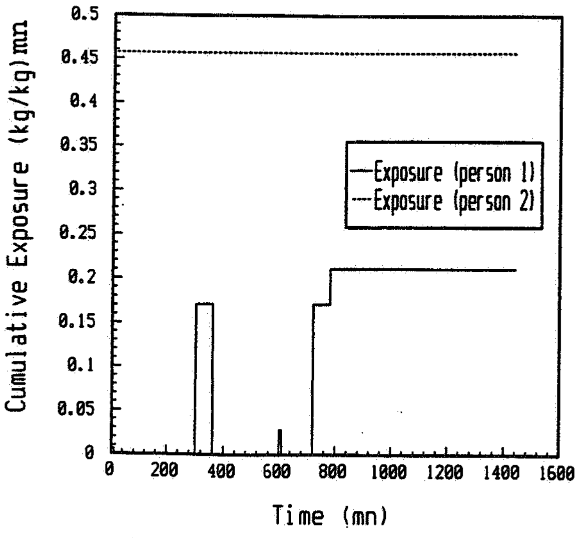

Figure 12 : Cumulative exposure.