AIR TRANSFERS BETWEEN ROOMS AND AIR QUALITY

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RESUME

Depuis 1986, le CSTB a entamé une étude à caractère fondamental et expérimental concernant les transferts d'air entre pièces. Cette recherche a pour but principal de développer et de valider un modèle aéraulique simple mais précis, adapté aux codes de calculs thermiques. Différents aspects connexes ont également été examiné et notamment l'aspect qualité de l'air.

Le présent article rappelle brièvement le contexte de la recherche et décrit les moyens expérimentaux utilisés. Une classification entre différents types de modèles aérauliques est proposée. Le nouveau modèle aéraulique, développé dans le cadre de cette recherche, est décrit. L'accent est mis sur les limites d'utilisation de ce nouveau modèle vis à vis du calcul des débits massiques entre zones et non plus seulement pour le calcul des conductances thermiques résultantes de ces débits. En particulier, l'article s'attache à montrer l'influence des gradients verticaux de température sur les débits entre zones et donc sur la qualité de l'air. Les phénomènes de double zone neutre sont plus spécifiquement étudiés.

ABSTRACT

Since 1986, CSTB is working on an experimental and theoretical study about internal mass and heat transfer between rooms. The main aim of this research is to develop and to validate a new aeraulic model designed for thermal computations. Nevertheless, various ways of research have been investigated and, in particular, the problems concerning air quality.

In this paper, the context of the research and the experimental means are briefly described. Definition of classes for the various kind of aeraulic models is proposed. The new aeraulic model is described. The paper focuses on the limits of using this model. In particular, the paper focuses on the influence of vertical temperature gradients. It is shown that the heat transfer does not depend upon the tempature gradients but the air flow rate depends on. In addition, double neutral plane phenomena are discussed.

1 . CONTEXT.

The main aim of this research is to evaluate the influence of taking into account the internal partition of buildings on the computation of thermal performances either of envelops components or of heating systems components.

Until these last years, performances were computed by using buildings unizone models. A building was described as an isothermal single volume ; the free gains (solar gains, heat losses of systems, ...) were assumed to be uniformly delivered.

To take into account the real internal partition of buildings leads to take into account non-uniform temperature fields. For instance, overheatings are in places more important than with an unizone hypothesis. Then, for example, the computed rate of recovery of the free gains is lower when taking into account the internal partition [1 à 4].

To compute with some accuracy the thermal performances of envelops or heating systems components in a multizone environment, the heat transfers between rooms have to be computed as accurately as possible. The main difficulty concerns the modelization of the heat transfers due to aeraulic transfers. To compute with accuracy the aeraulic heat transfers is seems a priori logical to use a model based on the computation of the pressure fields. In fact, for thermal computations (single goal of the aeraulic model : to provide thermal conductances due to air movements) an aeraulic model based on the computation of pressure fields is too much complicated. To use such a model leads to too long running times if annual simulations are needed. Moreover, sometimes problems of non-convergence occur [5 et 6].

A new model, adapted to thermal computation codes, has been developed. The application field of this new model has been defined in the framework of a global classification method for the various kind of aeraulic models (cf. §.2.1). At paragraph 2.2, the architecture of the new model is described. To validate this new model, an experiment has been designed ; the main characteristics of this experiment are given in section 3. In addition to the main aim of this new model, it could be use (as a simplified model) to compute the air flow rates between zones. The limits of validity of this model are discussed in paragraph 4 ; in particular, the problems of multiple neutral plan in an aperture are discussed.

2 . ARCHITECTURE OF THE NEW AERAULIC MODEL.

2.1.CLASSIFICATION OF AERAULIC MODELS.

A classification of the various aeraulic models has been designed. The models are classified depending upon their main application field. Then the different classes are :

- C1 Class - models with fixed scenarios for air movements between zones.
- C2 Class - models taking into account at each time step the evolution of the temperatures in the different rooms but without computing the pressure fields.
- C3 Class - sophisticated models based on the computation of the presure fields.

C1 class models are the simplest models and then the more common used for thermal computations. Their application field is strictly restricted to thermal computation codes. In a C1 class model, the air flow rate distribution between rooms (including with the outside of the building) is defined before to begin transient simulations. The air flow rate distribution can be defined by the software user or can be computed using a C2 or C3 class model. In any case, the air flow rate distribution does not change all along the simulation. At the very most, it is possible to define periodical time dependent scenarios.

C2 class models are designed to be used mainly for thermal computations. Nevertheless, with some restrictive conditions, they can be use to compute air flow rates. The new model we have developed is a C2 class model. At each time step, this model allows an accurate enough computation of the heat conductances due to air movements between rooms.

C3 class models to compute with accuracy the air flow rates. They take into account the wind effects, the air leakage, the buyancy effects, the ventilation systems ... C3 class models are used in htermal computation codes (CSTBât[(1)], ESP[(2)] ...) to compute in fact only heat transfers coefficients between rooms.

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(1) CSTBât : Code de Simulation de la Thermique du Bâtiment
CSTB Sophia Antipolis - France

(2) ESP : Environmental Systems Performance
University of Strathclyde - Departement of Architecture

As a conclusion of this presentation of the various kind of aeraulic models, what is to remain is that a complete aeraulic **module** (cf. Fig.1) would involve the different classes of aeraulic models. Because each one is adapted to a specific problem.

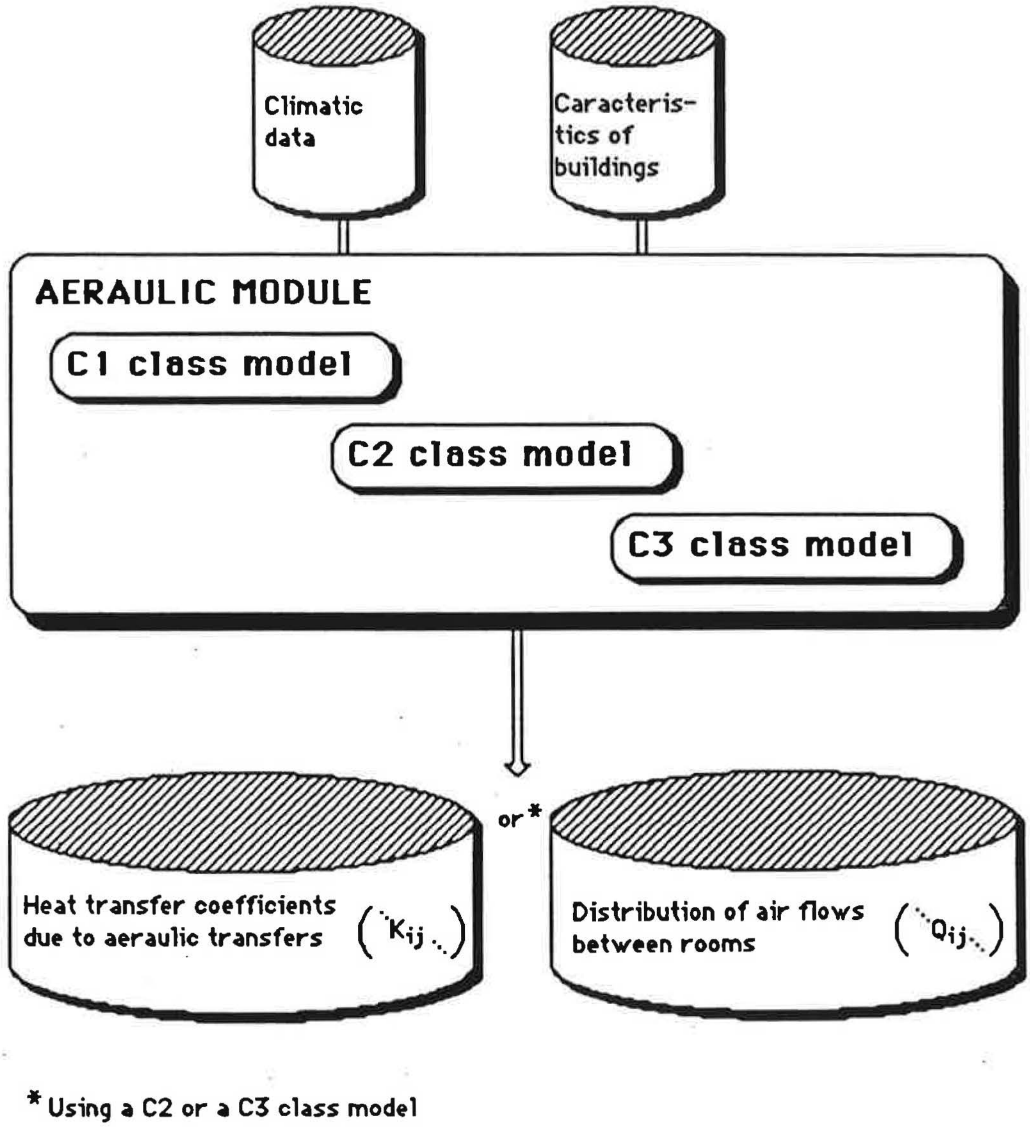

Figure 1 : Aeraulic module.

2.2. ARCHITECTURE OF A C2 CLASS MODEL

To compute thermal performances for a whole heating period, it is more important to take into account the variations of the internal air movements than the variation sof the air leakage and of the ventilation. For thermal computations, average values for the exchanges of air between the outside and the inside of a building can be used. Eventually, different average values will be used on one hand for winter and on the other hand for autumn and spring (only if a climatic analyse would shown that their are big differences upon the average values of air leakage because of very different average wind speed and direction and because of a bad airtightness of the building). In addition, mecanical ventilation can be defined as a periodical time dependent function.

Then, the aeraulic model involves a preprocessor to compute average distributions of air flow rates due to air leakage and ventilation. These calculations must be done for all the possible configurations, i.e. depending upon the possible status of the doors (open or close). The computations can be easily performed with a C3 class model assuming that all the temperature rooms are equal (because with this last hypothesis, the present C3 models runs very well taking few time for calculation).

At the end, the results are translated in terms of thermal conductances (named Ke_{lm}) between rooms. The values of Ke_{lm} are stored in a matrix. This matrix is named **D**(i, j, k, l, m).

- Index i is for the different period of the heating season (only if it is necessary, in general i = 1 ou 2).

- Index j is used if daily scenario for the mechanical ventilation are defined.

- Index k is to differentiate the various configurations (combination of all the possibilities to have open or close doors). The maximum vanue of index k depend upon the number of rooms and the hypothesis concerning the doors between rooms (behaviour of inhabitants).

- Index l and m are to point out the rooms between which the conductance Ke(i, j, k, l, m) occurs.

When this initialized phasis is ended (i.e. when the D matrix is full), the transient computations can run. The air movements between rooms are due on one hand to air leakage and ventilation and on the other hand to buyancy effect. The thermal conductances due to air leakage and ventilation are extracted from D matrix. The thermal conductances due to **buyancy effect** are computed through a simplified model ; his simplified model can be a relationship as Nu=f(Gr, Pr)*; such a model leads to define temperature dependent conductances between two nodes representing two adjacent rooms.

The global thermal conductance is computed by using a **coupling model**. The coupling model consists of a simplified relationship to calculate the global thermal conductance between two rooms knowing the thermal conductance due to air leakage and ventilation and the thermal conductance due to buyancy effect..

The architecture of a C2 model is summarized on illustration 2.

Important points.

The aeraulic model of C2 class involves in fact several submodels. They are :

- a model to compute discharge coefficients as a function of opening characteristics;
- a model to compute the D matrix (i.e. the thermal conductances due to air leakage and ventilation) ;
- a model to compute the thermal conductances due to buyancy effect ;
- a coupling model to compute the global conductances.

These different models are described in details in [7].

To identify the parameters of these models, an experiment, which takes into account the results of the previous one [8, 9], has been designed. This experiment is described further(cf. § 3).

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* Nu Nusselt's number
Gr Grasshof's number
Pr Prandlt's number

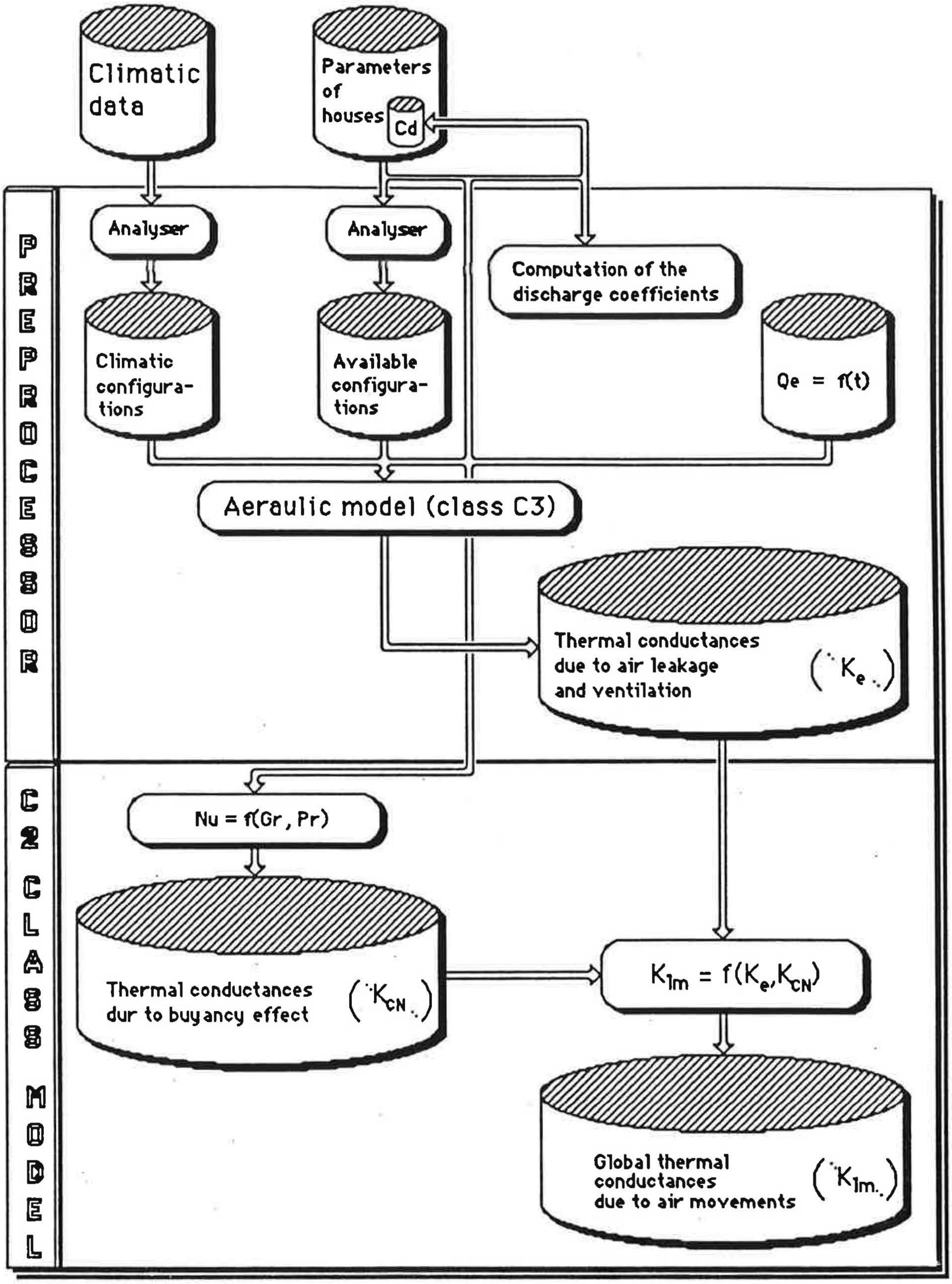


Figure 2 - Architecture of a C2 class aeraulic model.

3 . EXPERIMENT.

This experiment takes place in the DESYS test cell which is built within the area of the CSTB in Sophia-Antipolis. The DESYS test cell is described in details in [10]. The design, the instrumentation and the data acquisition system concerning the experiment about air transfers are described in details in paragraph 6 of [5].

Nevertheless, we give below some important informations concerning this experiment.

The aims of this experiment are :

- to provide some elements of reflection about the physical aspects of convection through an large opening ;
- to identify the parameters of reduce order models (as for example, a Nu=f(Gr, Pr) relationship) ;
- to provide experimental data to validate the whode C2 model.

The experiments aim to measure the heat transfer between two rooms (cf. Fig.3) when various conditions are applied. The heat transfer can be computed either by using the measured speed and temperature fields in the aperture or with a method of thermal balance.

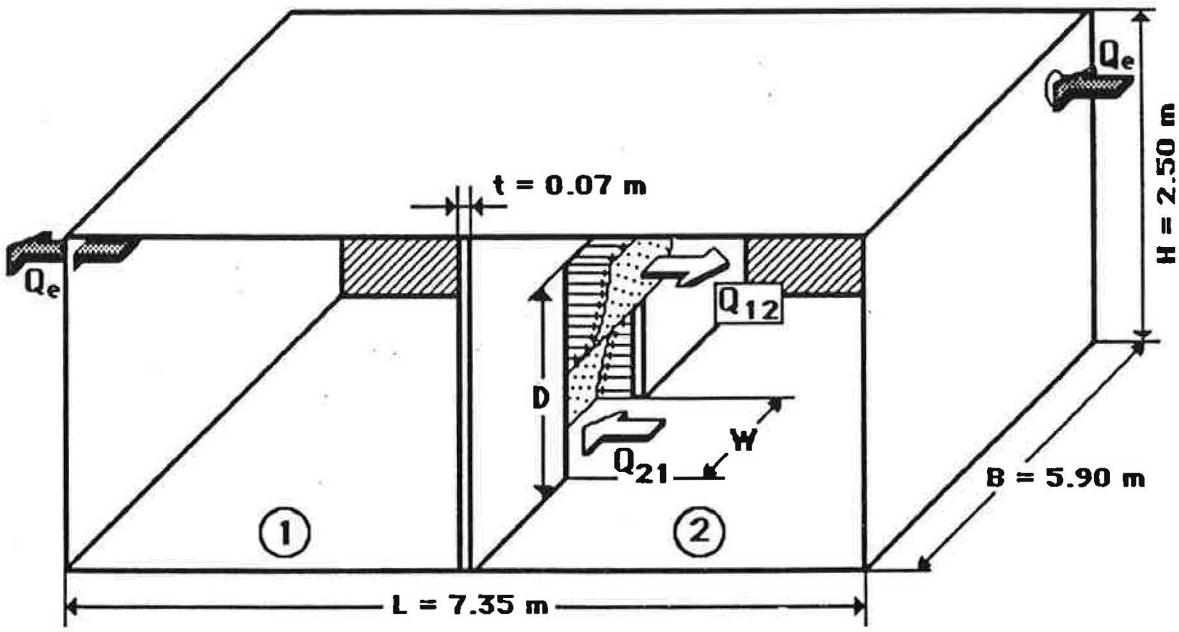


Figure 3 : Experiment.

The various conditions which can be applied are :

- fixed values for the heat fluxes in the two rooms (these fluxes can be positive - case of a heated room -, negative - case of a air-cooled room - or equal to zero - no heating or cooling system in the room -) ;
- different heating or cooling systems (convection - which depends on the system - inside one room can influence the air flow between the two rooms) ;
- air flow rate due to mechanical ventilation (there is an air-inlet in the room 2 and an air-outlet connected to a fan in the room 1, the rotation speed of the fan is adjustable) ;
- the dimensions of the opening (the surface area of the opening can be changed from some cm^2 to about 2 m^2).

The air speeds in the opening are measured with nine anemometric probes (marque DANTEC, type 54R10). These probes are attached to a movable cane (cf. Fig.4).

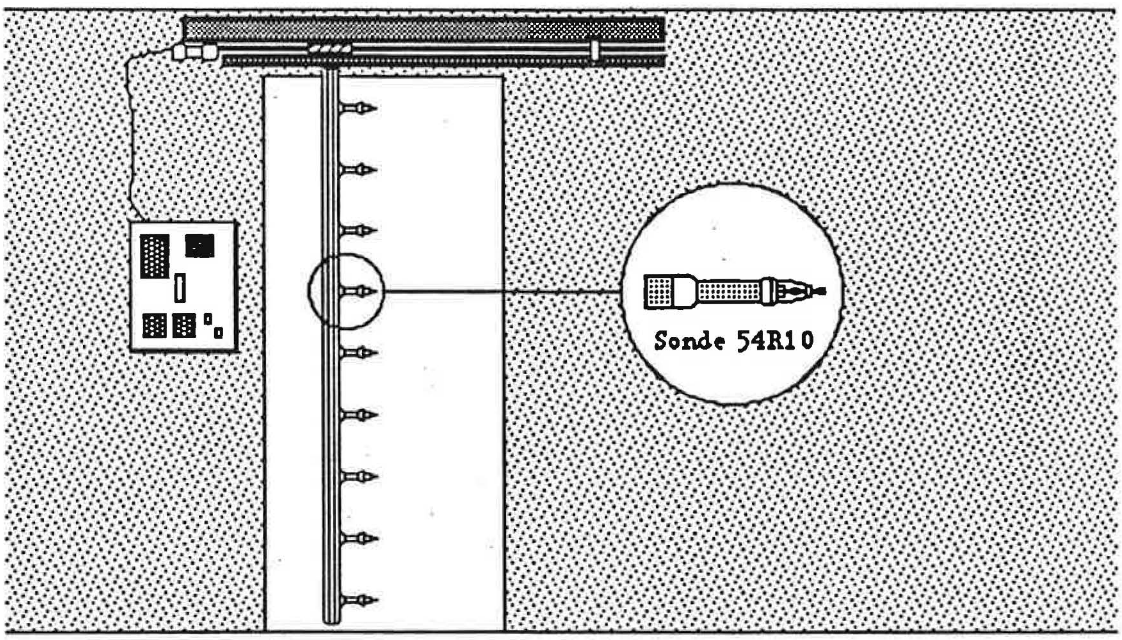


Fig.4 : Movable cane with its nine anemometric probes.

4 . MAIN RESUTLS.

A model to compute the heat transfer due to buyancy effect has been validated. This model (relationship Nu = f(Gr, Pr)) uses as caracteristical temperature difference **the difference between the average temperature of the rooms**. At the moment, the range of validity is $1.8\ 10^9 < Gr_D < 2.5\ 10^9$ and $D/H \geq 0.84$; moreover, this model is not very well adapted if heating or cooling system by pulsed air are used. The model is :

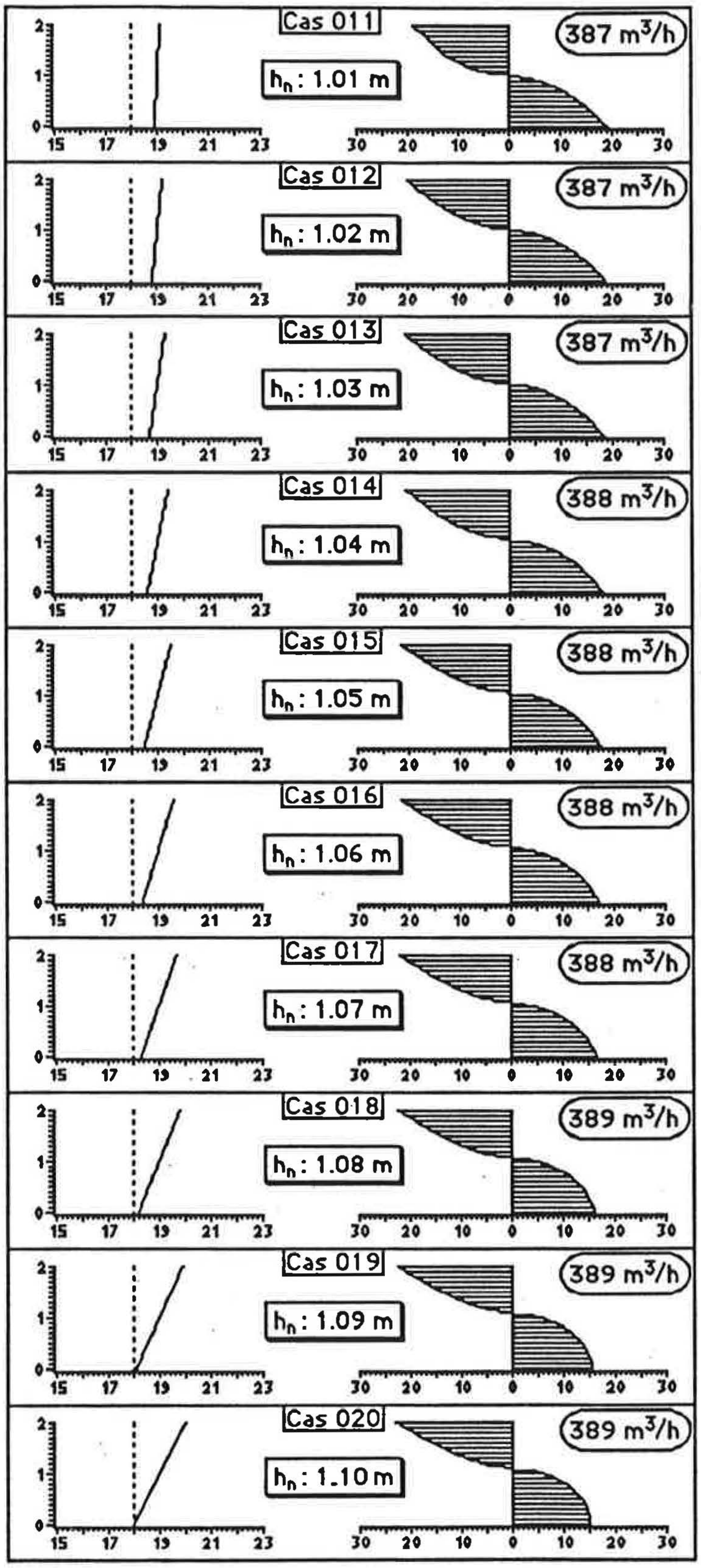
$$Nu_D = 0.4\ Gr_D^{0.5}\ Pr$$

By comparison with the previous similar models, the main advantage of this model is that the carcateristical difference of temperature is really the difference between the average temperature of the rooms. This is an advantage because is the aeraulic or thermal computation codes the only available temperature is the average temperature of the rooms (for experimental reasons, most of the previous similar models used the difference between the average temperature of the opposite walls).

In addition of evaluating heat transfer between rooms, the relationship Nu=f(Gr, Pr) can be used to evaluate very easily the air flow rate between two rooms with the only knowledge of the average temperatures of the rooms. But this calculation will give an enough accurate result only if the temperature profiles in the two rooms are almost linear (nevertheless, without leading to a phenomena of multiple neutral plan - cf. Fig.7 -).

To study the relationship "air flow rate = f(profiles of temperature)" a C3 class model can be used (this model is described in details in annex 3 of [7]) ; the C3 model we have developed is able to take into account any temperature profile. If, using the C3 model, it is proved that the temperature profiles have no effect (or a negligible one) on the computation of the air flow rates (for given average temperatures) then a C2 model can be use. Else, a C2 model cannot be used. The computations made with the C3 model have been validated by comparison with the measures made in the DESYS test cell.

As examples of results, (for the following dimensions of opening : w = 0.90 m et D = 2.00 m), we have shown that for some profiles of temperature air flow rates in the openining do not depend upon the temperature gradient in the rooms (cf. Fig.5).



Consider two air-tight rooms connected by a large opening (0.9 m x 2.0 m).

The temperature of room 1 is represented by the dooted line, the temperature of the room 2 is represented by the full line (look at left side of the pictures).

In this sequence, the temperature of the room 1 is constant, equals to 18°C. The temperature gradient in the room 2 increases gradually. At the begining (case 011), the gradient is 0.1°/m ; at the end (case 020) the gradient in room 2 is 1°/m.

The neutral plane (which cote is hn) is over the middle of the opening. The neutral plane goes up when the gradient in room 2 increases.

The air flows do not change a lot although the gradient in room 2 is very different betwenn case 011 and case 020. This happend because the temperature profile are linear. It would be different if they was not.

Fig.5 : Computed speed profile in the opening and air flow rate as a function of the temperature profile in room 2.

On an other hand, if the temperature profile are very different of linear profile then air flow rates depend upon temperature gradients. That is what the measurements made in the DESYS test cell have shown (cf. Fig.6).

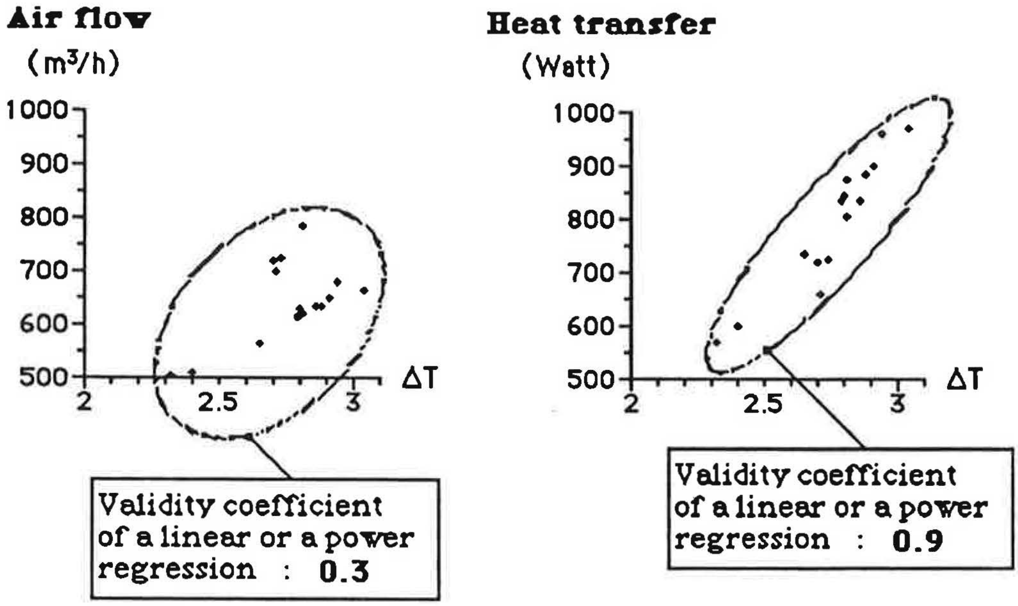


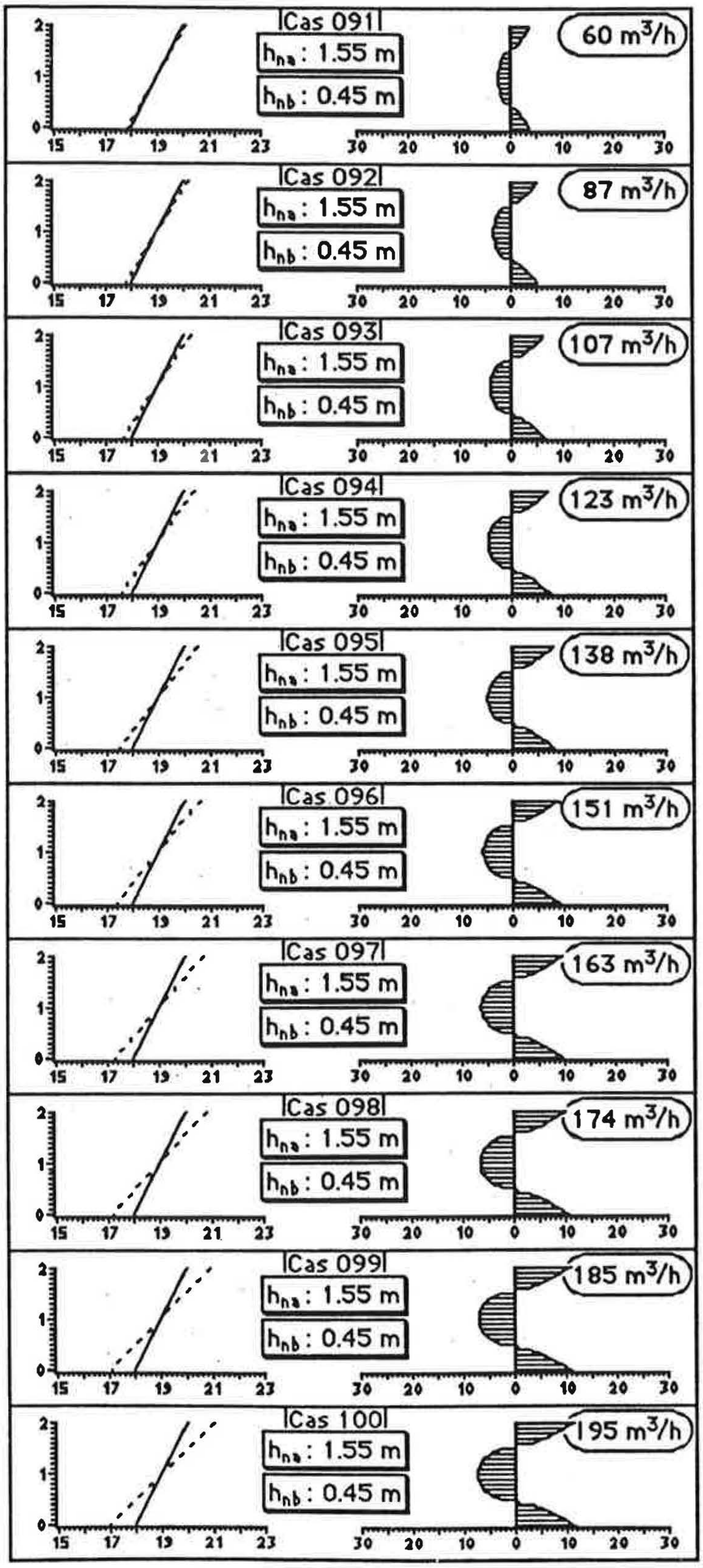
Figure 6 : Heat transfers (Φ) and air flows (Q) as a function of the difference between the average temperature of the rooms.

Comparing the two above figures, we notice that the experimental points representing the relationship $\Phi = f(\Delta T)$ are more close together than the points representing the relationship $Q=f(\Delta T)$. Then, for a same difference of average temperatures, the air flows between the two zones can be very different but the corresponding heat transfer is unchanged. That means that air flows can depend upon the temperature gradients (but, as it has been shown on figure 5, the dependence can be very slight if the gradient are constant and if there is only one neutral plane).

In case of double neutral plane.

Even if the temperature profiles are linear, a C2 class model can be not usable to compute air flow rate. It is so as soon as multiple neutral plane appear in the opening.

Let us consider the easy case of a double neutral plane as illustrated on figure 7 below :



In this sequence, the temperature of the room 2 (full line) does not change (average value 18°c with a vertical gradient of 1°/m).

The average temperature of room 2 is equal to the average temperature of room 1. Moreover, the average temperature of room 1 does not change but the vertical gradient changes (from 1.1°/m - case 091 - to 2°/m - case 100 -).

A double neutral plane appears in the opening. Although the average temperature are equal, the air flows are not equal to zero. The air flows depend upon the temperature gradient into the two rooms.

Fig.7 : Air exchanges between rooms with a phenomena of double neutral plane.

With this example, it is clear that although the temperature profiles are linear, it is not possible to compute the air flow rates by using a C2 class model. Moreover, to compute the air flow rates with a C3 class model, the model must take into account al least a certain stratification of the temperatures. Such a model has been exposed in annex 3 of [7].

5 . CONCLUSIONS.

The air flows in large openings, due to buyancy effect, can reached high values in compar with the values of the air flows due to air leakage and ventilation. For example, through a "standard" opening (about 0.9m x2 m), a difference of temperature of 0.1° creates a circulation of air of about 120 m^3/h ; 1° as difference of temperatures creates an air circulation of about 390 m^3/h. Concerning the diffusion of the pollutants, buyancy effect is a major phenomena.

To modelize the influence of buyancy effect, simplified models (C2 class) can sometimes be used. Such a model has been designed and partially validated. Its application field for the computation of air flows is limited to the case when the temperature profiles in th e rooms are almost linear and if there is no multiple neutral plane. If there is a multiple neutral plane (thls ca,n append with very simple temperature profile), the air flow rates can be very important although the average temperature of the rooms are equal (for instance, about 200 m^3/h through a "standard" opening for equal average temperature - 18°C - but with gradients of 1°/m in one room and 2°/min the other room).

If a C2 class model cannot be used, a C3 model must be used. But, to be very accurate, the C3 model has to take into account the vertical temperature gradients in the rooms. This kind of computations are not very complicated if the temperature profiles are known (inputs of the problem) but it becomes very complicated if temperature profiles are variables.

In addition, the ongoing experimental study would provide some data to validate a model to compute the discharge coefficient of the large openings. Further, some elements of reflection could be provide about the "physical" mean of the discharge coefficient and its relevant use.

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