

## AUTOMATIC GENERATION OF PARTITIONING AND MODELING ADAPTED TO ZONAL METHOD

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### ABSTRACT:

This paper presents the concept of a tool adapted to zonal models and devoted to the simulation of thermal dynamic phenomena in buildings. The aim of this tool is the automatic generation of zonal models requiring the minimum user's expertise.

The proposed tool uses a database to deduce the behavior of flows and thermal transfers. This database is composed of qualitative knowledge about elementary flows occurring in the building such as jets, plumes, and boundary layers, and of modeling knowledge ( experimental correlations, numerical or analytic solutions issuing from experiments or existing codes). The tool proposes a space partitioning based on the rules of expertise and respecting boundary conditions, and builds a simplified and suitable model.

The main feature of our model lies on the room partitioning based on the airflow pattern and varying over time to follow the evolution of the dynamic flows. The method chosen for the space partitioning is the *octree*.

### INTRODUCTION:

The management of energy consumption has become an absolute necessity for the occidental states. Numerical tools were developed to allow quickly prediction of the total thermal behavior in the buildings and their energy requirements. In these "energy codes", the system to be evaluate is the building itself and the study concerns the global energy exchange between the building and its environment.

Ventilation is an important factor in energy consumption of buildings; so, it has become necessary to study more specifically the airflow between the building and outdoor, and between the various zones of a building in order to control more specifically heating and ventilation systems. These approaches are known as "multizone models "; in this case, the building is subdivided into several zones connected with different physical methods.

Moreover, the request of comfort, and indoor air quality became increasingly important, pushing the

researchers to develop the use of Computational Fluid Dynamic codes (CFD codes). These simulation codes propose a detailed description of indoor air behaviors. They are proposing the construction of a grid for a room and solving the coupled energy and Navier - Stokes equations with iterative methods. These codes allow numerical simulations and are able to calculate parameters, which are not measurable. However, the grid construction, the description of the boundary conditions and the mathematical models of unsteady turbulent flows make these tools difficult to implement and require important computational resources. Moreover, some phenomena are still badly simulated by these codes.

In order to fill the gap between scientific knowledge and the need of design tool, a new family of models was born which is intermediate between the multizone models and CFD codes. This new approach is called "zonal models".

### ZONAL MODEL

The principle of zonal method is to divide the considered room into a number of cells in which are calculated the airflow characteristics (temperature, pressure, density, etc) assumed to be constant. Mass and energy exchanges are determined between the different zones. The division's macroscopic character is compensated by an accurate description of driving airflows. For dominant airflows (plumes, jets and boundary layers), specific laws are applied; outside this range, the laws are simplified. In other words, the principle of the zonal method is to subdivide a room into zones according to the type of the flow, in order to treat them with appropriate methods and to couple them by observing the boundary conditions. This processing consists in writing mass and energy balances.

Generally, the thermal and mass balance equations can be written for each zone as:

$$\begin{aligned} \frac{dM_i}{dt} &= \sum_{j=1}^n m_{ij} + m_{source} + m_{sink} \\ \frac{dQ_i}{dt} &= \sum_{j=1}^n q_{ij} + q_{source} + q_{sink} \end{aligned} \quad (1)$$

The first studies were lead by LEBRUN since 1970s (Bouia, 1993) and (Musy, 1999). After visualization of the airflows in climatic room, LEBRUN proposed, in the case of a heated room, six zones model based on an airflow pattern represented in Fig.1.

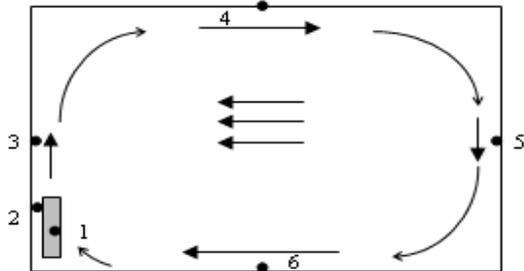


Fig.1: LEBRUN model

The next approaches were also based on fixed airflow directions and application of specific flow laws for plumes, jets, and boundary layers. They suffer from a too great rigidity as they were dedicated to the study of quite specific configurations, but this concept opens the way to a new modeling generation approach.

*Samira* model (Bouia, 1993) made it possible to overcome the rigidity obstacle and to model a greater number of situations. However, the formulation of the problem and the environment in which this tool has been developed limited it to study enclosure.

To enable the study of a greater number of flow patterns within a room and next the modeling of a whole building, zonal models had to be more flexible. The way towards a new type of approach was opened by WURTZ (Wurtz, 1995). He showed that the development of the zonal models in an object-oriented environment allowed the coupling of the airflow model with the others (thermal comfort model, conductive model...). MUSY has developed a model-generating tool called GenSPARK (Musy, 1999) that automates the process of assembling the appropriate modules to build the zonal model of a whole building.

In spite of these improvements, zonal models are still inflexible, do not allow the prediction of real complex airflows, and require a very great knowledge from the user to divide the room and to choose the appropriate models. This could be reasonable for steady flow case but not to represent the annual dynamic room behavior.

Therefore, our research consists in establishing a method to analyze the airflow and building a tool that generates zonal models with a minimum user's expertise. This tool uses a database which is built from qualitative knowledge of the elementary flows (jets, plumes, boundary layers), and from modeling knowledge (numerical or analytical solutions resulting from experiments or existing codes) to

deduce the flow and the thermal transfer behaviors. While being based on the expertise rules and by respecting boundary conditions in the room, the code performs a space partitioning and builds a suitable simplified model.

The chosen method for space partitioning is the *octree*, which provides flexibility to our model.

### OCTREE METHOD:

Dating back to the late 1970's, the *octree* is one of the most common hierarchical representation based on a recursive and regular 3D space partitioning. It is derived from *quadtree* (2D representation). It has been used as a domain decomposition method for computer graphics and solid modeling (CHARLTON et al, 1997).

The octree (octal tree) is built from a box that encompasses the entire domain of the problem (the room in our case), located at the root of the tree. This box is recursively divided into eight similar cubes or octants. The relationship between the octants is represented by a tree structure (Fig.2b). Each octant is assigned an identification tag that gives the exact location of each cube in the octree (Fig.2a).

The process of subdivision continues as far as stopping a criterion is reached. In our case, this criterion is either the octant is homogeneous (a single specific or ordinary flow is occurring in the octant) or the minimum size of the octant defined by the user is reached (several flows are occurring in the octant). In the second case, we get a heterogeneous octant. This one is made homogeneous by selecting and allocating to the octant the most dominant airflow. Finally, we obtain two types of terminal octants (leaves of the tree):

- Specific homogeneous octant where occurs a driving airflow (plume, jet, boundary layer);
- Ordinary homogeneous octant which contains an ambient air.

The octree partitioning method has been chosen for this research for the following reasons:

- An octree-partitioning is an adaptive method that fits the geometric model of the specific flows.
- The minimum size of octants (zones) can be chosen according to accuracy of simulation results.
- This method can deal with different geometric models: polyhedrons, quadrics, etc.
- Adjacent octants are retrieved for octree structure.
- Once generated, the analysis of an octree structure is very fast: we start from a complex

global phenomenon (several competing airflows) then we simplify it by isolating each local phenomenon in an octant.

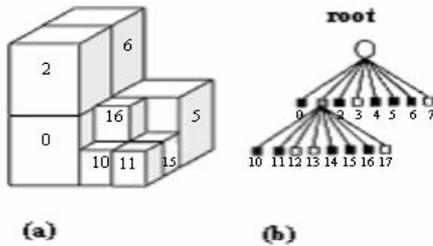


Fig.2: a) Octants, b) Octree structure

### PRINCIPLE OF THE AUTOMATIC GENERATION OF ZONAL MODEL:

The tool we are developing is part of an automatic simulation tool for aeratic and thermal phenomena in building. It can be divided into five parts : analysis tool, database, partitioning tool, flow solution and visualization tool (Fig 3.).

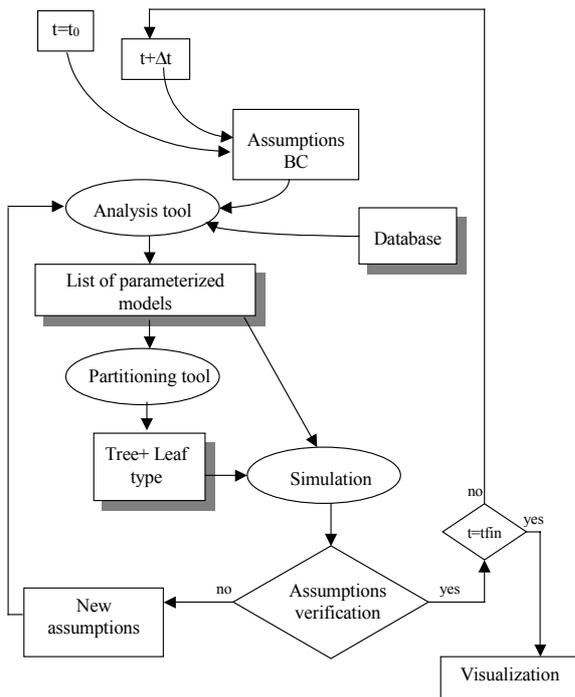


Fig. 3: Structure of the generator of zonal model  
Linkage of analysis, partitioning and simulation  
BC: Boundary condition

After achieving its own expertise and choosing the suitable analytical model, the generator of zonal models subdivides the studied room and connects the terminal octants (zones) by mass and energy transfers. The system of equations obtained will be

solved and the results will be displayed. The process finishes when hypothesis and solutions are coherent.

The main functions of the generator of zonal models are:

- The identification of elementary flows thanks to expert rules.
- The determination of the limits of the elementary flows, which represent the validity of analytical model domains.
- The selection of the analytical appropriate model (including the laws that describe the flow delimitation) in a database for each elementary flow.
- The partitioning of the room by observing the boundary conditions.
- The connection of the local models with the mass flow rate and heat transfer exchange.
- The various modules of the generator are developed below.

### ANALYSIS TOOL:

This module contains the expert rules describing the problem (geometry and physical boundary conditions). We assume that all computational domains could be represented by a set of vertices.

The analysis tool allows interpreting the boundary conditions and detecting the flows which are dependent on them. The most adapted analytical model is chosen automatically in the database to represent the detected airflow (CF Fig. 3). This model contains the elements that allow delimitation of the flow holds. The employed method will enable us to manage the conflicts between several flows thanks to test rules.

For any problem, the analysis tool has to answer these questions:

- Which are the causes of the flow?
- Which is the nature of the flow issued from these causes?
- Which is the specification of the elementary flows? (Turbulent or laminar, warm or cold, horizontal or vertical...).
- Which are the boundaries of the elementary domains?
- Which is the most appropriate model for the elementary flow?

All this information is stored in a string, which can be read at any time during the computational process. For each elementary flow, the choice of an appropriate model in the database is done with rules which test the string of the qualitative specifications

of the flow, the geometric descriptors and the boundary conditions.

After answering the above-mentioned questions, the tool applies the elementary model to the context (boundary conditions and geometry), then gives a parameterized model.

### DATABASE:

The database tool includes the analytical models and the empirical laws. The models are stored as a string referred to a file that contains the geometrical flow descriptors (trajectory equation, thickness...), the flow specifications, and the boundary conditions.

The thermal and aeraucic phenomena found in the building are the thermal plumes, jets and boundary layers. The next paragraph will explain the details of each elementary flow models.

### **Plume modeling:**

A plume is a region of rising warm air. By contacting with the thermal sources, the ambient air warms up and becomes less dense, and then it rises by natural convection, pushes and pulls the surrounding air, thus forming a plume of hot air.

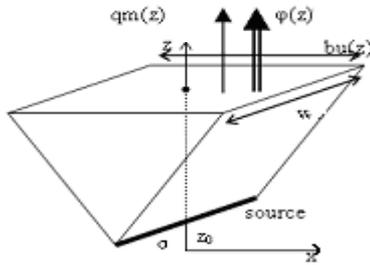


Fig.4 a) : Free plane plume

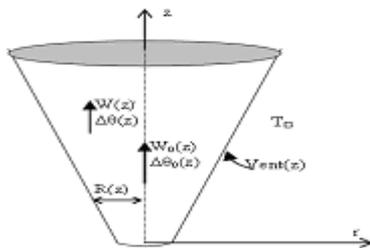


Fig.4 b) : Free axisymmetric plume

For this research, the models chosen are those of MANZONI and INARD.

### **MANZONI model:**

MANZONI developed this model in case of displacement ventilation and assumes that the plumes which develop over a punctual or linear source are axisymmetric (Manzoni et al, 1997). Furthermore, this model assumes that velocity and temperature profiles in the plume are auto-similar in form, and follow the Gaussian profile

The set of equations (2) is used to quantify mass and energy rates in the plume.

$$\begin{aligned} R(z) &= \frac{6\alpha}{5} z \\ W_0(z) &= \left( \frac{3F_0(1+\lambda^2)}{2\pi} \right) \left( \frac{5}{6\alpha} \right) z^{-1/3} \\ \Delta\theta_0(z) &= \left( \frac{2}{3\pi^2} \right)^{1/3} \frac{(F_0(1+\lambda^2))^{2/3}}{g\beta\lambda^2} z^{-5/3} \end{aligned} \quad (2)$$

### **INARD model:**

In this part, we will describe the thermal characteristics of bidimensional turbulent plume derived from a heat source using the *Inard et al.* equations (Musy 1999). This model can be used to describe the plumes which develop over a convective heater.

$$\begin{aligned} Bu &= \frac{2E_0}{\sqrt{\pi}} \left( 1 + \frac{St(1+\lambda^2)^{1/2}}{3\lambda E_0} \right) (z-z_0) \\ Um &= \left( \frac{6\lambda(1+\lambda^2)^{1/2}}{3\lambda(Cf + \sqrt{2}E_0) - (2(1+\lambda^2))^{1/2} St} \right)^{1/3} \left( \frac{\phi g \beta}{\rho_0 C p_0} \right)^{1/3} \\ \Delta T_m &= \left( \frac{\phi g \beta}{\rho_0 C p_0} \right)^{2/3} \left( \frac{3}{2St(1+\lambda^2)^{1/2} + 6E_0} \right) \left( \frac{1}{g\beta(z-z_0)} \right) \\ &\quad \left( \frac{4(1+\lambda^2)}{3\lambda} \left( 3\lambda(Cf + \sqrt{2}E_0) - (2(1+\lambda^2))^{1/2} St \right) \right)^{1/3} \end{aligned} \quad (3)$$

The plume airflow rate is:

$$q = \frac{\sqrt{\pi}}{2} \rho_0 U_m B_u \quad (4)$$

### **Boundary layer modeling:**

The boundary layers develop along the vertical walls from which the surface temperature is very different from the ambient temperature in the room. We can represent a validity domain of a boundary layer by rectangle whose dimensions are given by the wall and the maximum boundary thickness (Table1).

*Table 1*  
*Empirical laws for the maximal boundary layer thickness*

	Laminar boundary layer thickness	Turbulent boundary layer thickness
Natural convection	$5LRa^{-1/4}$	$0.527LR_L^{-1/10} Pr^{-11/30}$
Forced convection	$\frac{5L}{\sqrt{Re_L}}$	$5(0.37L Re^{-1/5})$

Allard et al. proposed the boundary layer model that we use. It expresses the airflow rate as a function of the difference between wall surface temperature and ambient air temperature (Inard et al, 1996):

$$m(z) = 0.004(T_w - T)^{1/3} z \quad (5)$$

Where,  $z$  is the vertical distance between the considered point and the boundary layer origin.  $T$  is the air temperature near the wall, and  $T_w$  is the wall surface temperature at the  $z$  height.

#### Jet modeling:

The study of the jets covers infinite flow patterns. In fact, the categories of the jets are not only function of the type of air supply device (axisymmetric, radial, etc.) but also of the blowing direction (horizontal or vertical), of the confinement.

For this reason, after an inventory of the jet description laws proposed in the bibliography, we tried to release some models applicable to the configurations frequently found in the buildings. In the following, we present the three principal jets families found in buildings.

#### Bidimensional jet:

The bidimensional jet is a jet resulting from a diffuser whose aspect ratio is higher than 40 (Awbi, 1991). The flow presents 2D characteristics and is studied in the perpendicular plan to the duct opening.

The velocity decay is given by (Meslem, 1997):

$$\frac{U_m}{U_0} = K_v \sqrt{\frac{h_0}{x}} \quad (6)$$

$K_v$  is an empirical constant decay and  $h_0$  is the dimension of the jet inlet.

The total flow mass in the jet is given by:

$$\frac{qm(x)}{qm_0} = 1.065K_v C_u \sqrt{\frac{x}{h_0}} \quad (7)$$

Where,  $C_u$  is the proportionality factor related to the air velocity in the jet.

#### Axisymmetric jet:

The axisymmetric jet is a jet resulting from a circular inlet. The axial velocity evolution of the circular jet is expressed by:

$$\frac{U_m}{U_0} = K_v \frac{d_0}{x} \quad (8)$$

Moreover, the total flow mass rate is given by:

$$\frac{qm(x)}{qm_0} = 5.73K_v C_u^2 \frac{x}{d_0} \quad (9)$$

#### Three-dimensional jet:

Jets, which are neither plane nor circular, are referred as three-dimensional jets. In practice, jets issued from aspect ratios openings  $1 < b/h < 40$  usually fall in this category (Awbi, 1991). The velocity profiles in the plane ( $x, z$ ) are self-similar and follow a law of the type:

$$\frac{U}{U_m} = \exp\left[-a\left(\frac{z}{x}\right)^2\right] \quad (10)$$

The constant "a" varies from 55 to 68 (Meslem, 1997).

The various implemented models in the database are presented in the table (2).

#### PARTITIONING TOOL:

After the phase of analysis and choice of the implemented models, we obtain a file containing the geometrical and physical characteristics of the models. This file is exploited by the partitioning tool which aims at a hierarchical grid generation (Cf. Fig. 3). The geometrical models allows delimiting the domains containing specific flows (specific homogeneous octant).

The partitioning tool is based on the octree method presented above (Cf. Octree method). The terminal octants (zones of the room) at the leaves of the tree represents either specific homogeneous zones containing plume, jet or boundary layer airflow or ordinary homogeneous zones containing ambient air.

We present in Fig.5 a 2D partitioning of a room with a specific airflow (free plume).

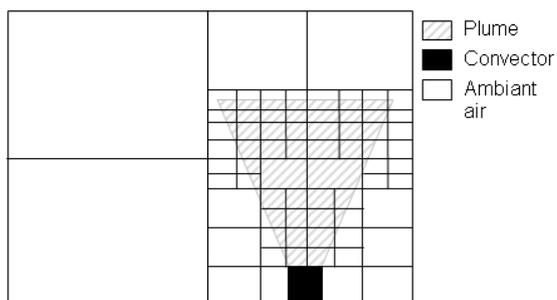


Fig. 5 : 2D Partitioning

### SIMULATION:

In each ordinary homogeneous octant (where no specific flow occurs), mass and heat balances are written. This enables us to calculate the pressure and the temperature, and to reconsider the assumptions of the mass airflow rates and the heat flows. In the other octants, the specific empirical law already verifies mass continuity, where temperature and heat balance equations are considered.

We iterate thus until the convergence of the phenomena in each octant. The possibility to know the adjacent octants by the *Octree* method is exploited for the calculation of airflow rates and heat flows between connected octants. It is important to note that a zone has six or more neighboring zone, so balance equations have a varying number of terms.

So, we have a local resolution method different from the global matrix methods generally used for zonal model resolution (Wurtz *et al.*, 2001).

### CONCLUSION:

The method presented in this paper enters within the framework of the automation of modeling tools and simulation of airflow and thermal phenomena in the building, in order to generate zonal models. Compared to the previous zonal models, the originality of this work is the specification of an automatic tool which makes possible to analyse flows inside the studied room: starting from the boundary conditions it detects all the thermal and aeraulic phenomena that occur in this room.

The zonal model generator is based on an adaptive space partitioning, the octree method. Therefore, we adapt the local resolution (octant) of the spatial partitioning to the scale of the encountered phenomenon (specific or ordinary flow).

Finally, we have presented an approach allowing the dynamic management of a set of flows varying over time.

Tab 2  
Jets characteristics

	Thickness	Jet Extinction abscissa	Linear mass air flow rate
Isothermal free Jet	$bu = 2.C_U x \sqrt{-\frac{\ln(0,01)}{\ln 2}}$ (11)	$X_f = h_0 \left(\frac{K_v U_0}{0,25}\right)^2$ (12)	$\frac{qm(x)}{qm_0} = 2,13.C_U K_v \sqrt{\frac{x}{h_0}}$ (13)
Isothermal wall jet	$bu = \left(\sqrt{-\frac{\ln 0,01}{0,937}} + 0,14\right) C_U x$ (14)	$X_f = h_0 \left(\frac{K_v U_0}{0,25}\right)^2$ (15)	$\frac{qm(x)}{qm_0} = 1,054 C_U K_v \sqrt{\frac{x}{h_0}}$ (16)
Anisothermal horizontal free jet	$bu = 2.C_U x \sqrt{-\frac{\ln(0,01)}{\ln 2}}$ (17)	$X_f = h_0 \left(\frac{K_v U_0}{0,25}\right)^2$ (18)	$\frac{qm(x)}{qm_0} = 2,13.C_U K_v \sqrt{\frac{x}{h_0}}$ (19)
Anisothermal horizontal wall jet	$bu = \left(\sqrt{-\frac{\ln 0,01}{0,937}} + 0,14\right) C_U x$ (30)	$X_f = 1,6 \sqrt{\frac{A_0}{Ar_0}}$ (31)	$\frac{qm(x)}{qm_0} = 1,054 C_U K_v \sqrt{\frac{x}{h_0}}$ (32)

	Temperature decay law	Trajectory equation	Constants
Isothermal free Jet			CU=0,1 Kv=2,47
Isothermal wall Jet			CU=0,068 Kv=3,5
Anisothermal horizontal free jet	$\frac{\Delta T_m}{\Delta T_0} = K_T \sqrt{\frac{h_0}{x}}$ (33)	$y = 0,7 \cdot \frac{K_T}{K_v^2} \cdot \frac{g \cdot \beta \cdot \Delta T_0}{U_0^2 \cdot h_0^{3/2}} \cdot x^{5/2}$ (34)	CU=0,109 Kv=2,62 CT=0,14 KT=1,99
Anisothermal horizontal wall jet	$\frac{\Delta T_m}{\Delta T_0} = K_T \sqrt{\frac{h_0}{x}}$ (35)		CU=0,074 Kv=3,67 CT=0,095 KT=2,79

## NOMENCLATURE:

$B_u$ : Plume or jet width [m]  
 $C_u$ : constant  
 $d_0$ : jet diameter [m]  
 $E_0$ : entrainment factor  
 $g$ : gravitational acceleration [m.kg<sup>-1</sup>.s<sup>-2</sup>]  
 $h_0$ : diffuser height [m]  
 $h(x)$ : jet width [m]  
 $K_t, K_v$ : empirical coefficients  
 $M_i$ : mass in the zone I [kg.s<sup>-1</sup>]  
 $m_{ij}$ : rate of mass flow from zone I to zone j [kg.s<sup>-1</sup>]  
 $m_{source}$ : rate of mass supplied by the source in the zone [kg.s<sup>-1</sup>]  
 $m_{sink}$ : rate of mass removed from the zone [kg.s<sup>-1</sup>]  
Pr: Prandtl number  
 $Q_i$ : the heat energy in zone I [W]  
 $q_{ij}$ : the rate of heat energy from zone I to zone j [W]  
 $q_{source}$ : the rate of heat energy supplied by the source in the zone [W]  
 $q_{sink}$ : the rate of heat energy removed from the zone [W]  
 $R(z)$ : panache radius [m]  
Ra: Rayleigh number  
Re: Reynolds number  
 $U_m$ : maximum mean plume or jet velocity in a cross section [m.s<sup>-1</sup>]  
 $W_0(z)$ : axial velocity in plume [m.s<sup>-1</sup>]  
 $\Delta\theta_0(z)$ : difference between plume temperature and ambient temperature [°C]

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