DESCRIPTION INDUCED BY MODELISATION METHODS IN THE CASE OF BUILDING THERMAL SIMULATION

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ABSTRACT

Two main modelisation techniques are the analytic and systemic methods. After a presentation of each method applied to building simulation, this paper emphases the benefit of systemic modelisation for multizone cases. Using a conceptual description of a building issued of previous method, one particular sub-system appears naturally, i.e. the thermal zone. Then, the physical coupling of thermal zones can simply be solved. Building description through data structures, required for thermal simulation, is easily reached. The detail of our organisation is given in the case of our multiple model software, *CODYRUN*. Because of our resolution sheme, the main problem is the establishment of a thermal zone model. So, the computer generation of one zone nodal model is explained.

INTRODUCTION

At the beginning of this work, our objective was to realize a design tool suitable for professionals and usable by researchers. More precisely, *CODYRUN* is a multizone software integrating both natural ventilation and moisture transfers. During a simulation, one of its most interesting aspects is to offer the expert thermician a wide range of choices between different heat transfer models and meteorological reconstitution parameters models. The aim may be to realize studies of the software sensitivity to these different models, in order to choose those that should be integrated in a suitable conception tool. It was developed on a PC micro computer with *Microsoft WINDOWS* user-friendliness interface.

Considering the thermal behaviour of a building, its thermal state is determined by the continuous field of temperatures, concerning all points of the physical limits of the building. The constitution of a reduced model is possible by assuming some simplifications, as mono-dimensional conduction in walls or well mixed air volumes of each thermal zone. In this case, zones and wall temperatures are the main unknown variables of the problem.

ANALYTIC METHOD APPLIED TO THERMAL BUILDING SIMULATION

As in other fields, computer simulations and before modelisation methods became key words. History of modelisation shows the domination of the analytic method. This procedure means that it's possible to reduce the studied object into elementary parts and that it's possible to build a model of the object from these parts. So, the building system is considered as split up into simple systems, like walls, windows, air volumes, HVAC systems, and so on. Then, it's necessary to study them one by one and to understand the existing interactions. To apply this method to heat transfer in buildings, we'll consider an important component of a building, a wall. The thermal field expresses the instantaned balance between conduction, convection and radiation heat transfers. For each of these phenomena, analytic models are available and their assembly will build a wall thermal model. For conduction transfers, inputs for each side of the wall (indiced respectively by 1 and 2) are ϕ_{CV} (convective flux), ϕ_{SW} (short wave flux) and ϕ_{LW} (long wave). The outputs of the model are temperatures inside the wall, *{Ti}*, and surface temperatures T_{s1} and T_{S2}

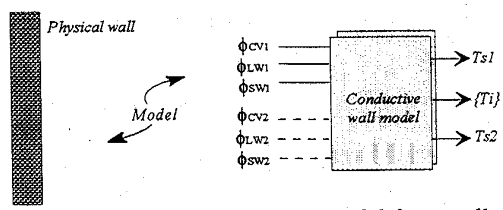

Fig. 1 : *Conduction model for a wall*

Concerning convection heat transfer, we choose a simple model considering surfaces and air temperatures (respectively T_s and T_a), illustrated by figure 2.

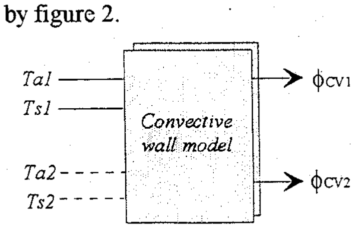

Fig. 2 : *Convection model for a wall*

For long wave exchanges, the chosen model computes long wave fluxes, ϕ_{LW}, on indoor and outdoor surfaces. One meteorological input is the sky temperature, T_{sky} (another choice could be the outdoor radiant temperature). This model also needs the indoor surface temperatures, $\{T_s\}$.

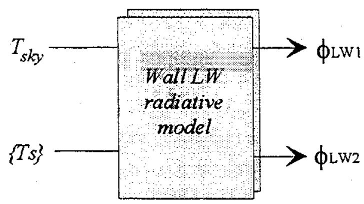

Fig. 3 : *Long wave exchanges*

Then, we consider on fig. 4 the simple following building, constituted by 3 walls (A, B and C) and a glass-window.

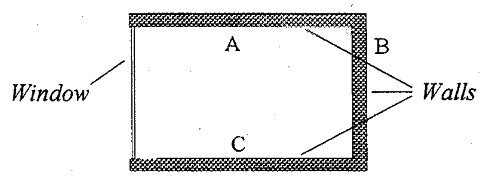

Fig. 4 : *Simple building vue*

Doing the same as for walls, it is possible to build thermal model for windows and air volumes. By assembling each model (conduction, convection, ...) of each component (walls, window, air volume), the analytic methods leads to the construction of a thermal model for the whole building, as shown on figure 5.

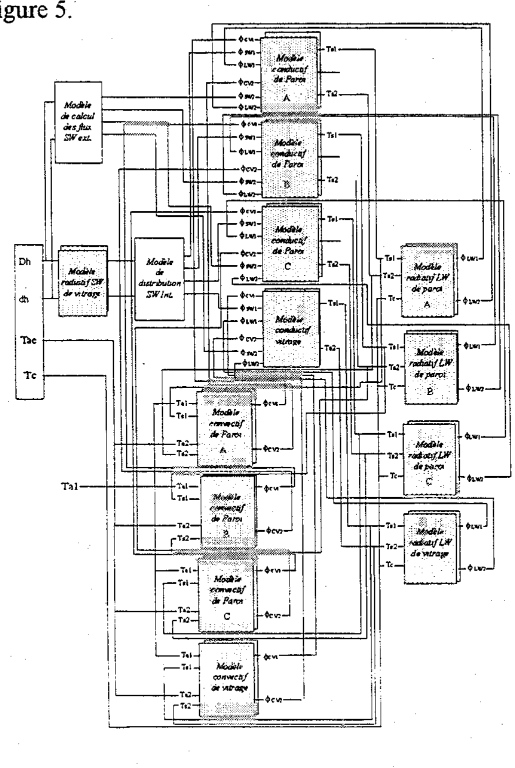

Fig. 5 : *Global model of the simple building*

This figure is not pretending to be readable, but because of its complexity, we can obviously predict some problems in case of real buildings. This analytic method is in fact really close to physics laws. The main consequence is that simulation tools issued of the analytic modelisation method do not suit to professional users like architects. *TRNSYS* could be one of these [Trnsys 79]. In addition, considering the building description, the natural description for this method needs to inform all the connections between the different models. So, this anatomic splitting up is not giving the designer much information about the way to describe the building, in terms of data structures.

SYSTEMIC ANALYSIS

We'll show that this method allows us to council detailed modelisation and design orientation of our work. Bertalanffy [Bertalanffy 68] associates the systemic method to the question "*What does it make ?*", in opposition to analytic method, dealing with "*What is this made of ?*". The general system theory considers a system as an evoluting black box, displayed on figure 6, in interaction with environments (physical, legacy, ...), having aims and realizing functions.

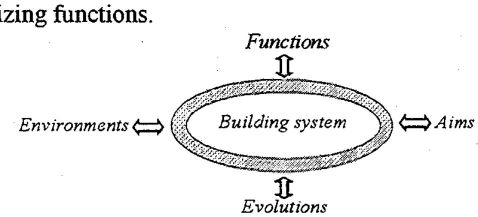

Fig. 6 : *The General System*

Robin gives this definition of a building : *a physical envelop, space close and covered, protecting of all outdoors actions an internal space* [Robin 91]. In regard to building thermal behaviour, considering its partitioning into rooms (for social, structural or economic reasons), the aim is to control the indoor climate of the whole building or of some of it parts. So, the aim of thermal design is showing the emergence of an entity, the thermal zone. It means one or few rooms, having similar thermal behaviour (including same HVAC conditions). A thermal zone is constituted of components, such as air volumes, HVAC systems, walls in contact with air volumes, ... In regard to this new object, next figure illustrates our first tree-like structure for a 3 story building:

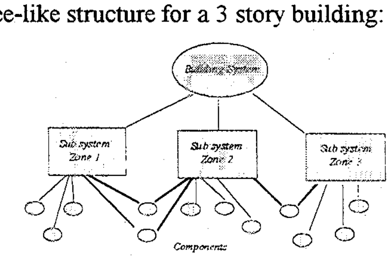

Fig. 7 : *Systems hierarchy*

Relations between the three levels of description (i.e. lines on the previous figure) exprimate belonging relations. So, if one room is considered as a thermal zone, we can say that the room belongs to the building. If this room is air conditioned, the HVAC system belongs to the zone. As given our definition of a thermal zone, a component may belong to two zones (bolded lines). Such a component (separation wall or opening) is performing the thermal coupling of the separated zones. To make the description easier, we prefer to introduce another object, the *Inter-zone*, to which the coupling components belong.

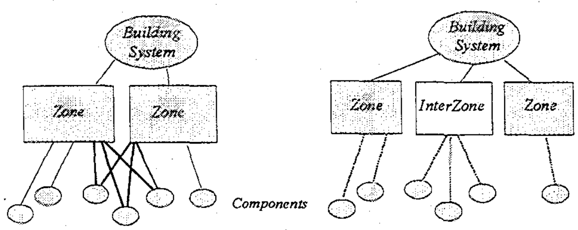

Fig. 8 : *Systemic and conceptual building description*

CODYRUN BUILDING DESCRIPTION

The first purpose of our work has been to allow - as far as heat transfer modes, airflow calculation and meteorological data reconstitution are concerned- the integration of diverse interchangeable physical models in a single software tool for professionnal use, *CODYRUN*. The designer's objectives, precision requested and calculation time consideration, leads us to design a structure accepting selective use of models [Boyer 93], taking into account multizone description and airflow patterns. Concerning thermal aspects, the matricial model constitution looks like ESP [Clarke 85] and airflow model can be compared to AIRNET [Walton 84]. A main difference is our objective of professionnal use, involving a user-friendly interface.

The three main parts of *CODYRUN* are the building description, the simulation program and the operation of the results. As far as the description is concerned, we have been brought to break down the building into three types of entities which are the following ones : firstly, the *Zones* (from a thermal point of view), the *Inter-zones* partitions (zones separations, outdoor being considered as a particular zone) and finally, the *Components* (i.e. walls, glass partitions, air conditioning system sets, ...). The following tree-like structure illustrates our organisation :

Building —— *Zone(s)* — *Component (s)*

Building —— *Interzones* - *Component (s)*

Fig. 9 : *Data organization*

Then, the user's interface proposes to begin the description of a building with the following window :

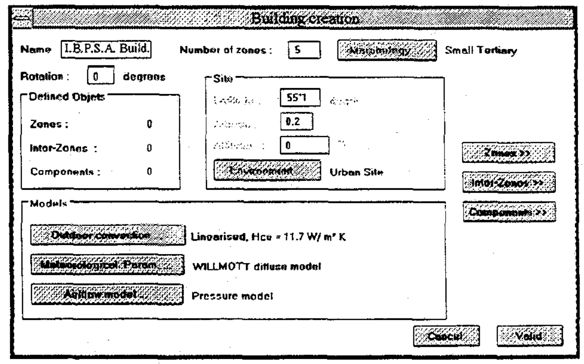

Fig. 10 : *Building description window*

A few information fields are associated to the building, as name and morphology, or its location (latitude, environment, ...). The border tilted *Defined objets* remembers the number of zones, interzones and components previously attached to the building. The number of zones, informed during building creation, is a data that won't be modifiable. The choice we made was to condition the building description by the number of zones. The push buttons zone, interzone and components make possible the access to this previously defined entities. The access to the models linked to the entity "building" is also possible from this window through the push buttons of the screen part called "models". It is possible in this way to select the chosen models for outside heat convection transfer, reconstitution of meteorological parameters (diffuse and sky temperature) as well as the airflow model.

The second presented window is concerning the thermal zone entity. The main associated datas are a name (that will be needed later to affect components to this zone or for interzone location) and the volume. The push buttons < and > allow access to the window concerning respectively the previous and next zone.

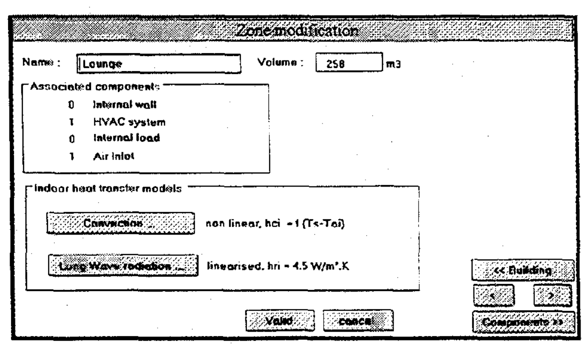

Fig. 11 : *Zone description window*

After filling building and zones windows, it's necessary to give informations about Interzones. The name will be used to affect components. Each Interzone has a type, listed in the border tilted *Type*.

- This information is needed by models (for an opening affected to an interzone, the airflow model needs to know if the interzone is vertical or horizontal) or in order to control components affectation (for ex., no wall on slab in a vertical indoor interzone).

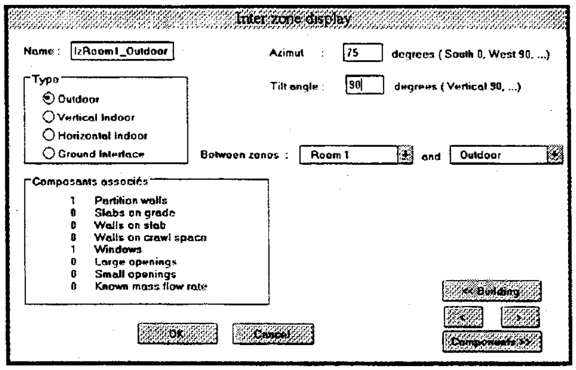

Fig. 12 : *Interzone description window*

The description now corresponds to a building squeletton. To complete the building, the following board lists the components already integrated :

Zone components	Interzone components
internal wall	*partition wall*
HVAC system	*slab on grade*
internal load	*wall on slab*
air inlet	*wall on crawl space*
	window
	large opening
	small opening
	known air flow rate

For all the components, name, type (among the proposed component types), and name of the entity (zone or interzone) it belongs to is to be indicated. The following figure is corresponding to an HVAC system, attached to a zone (by using the list box containing the names of the zones).

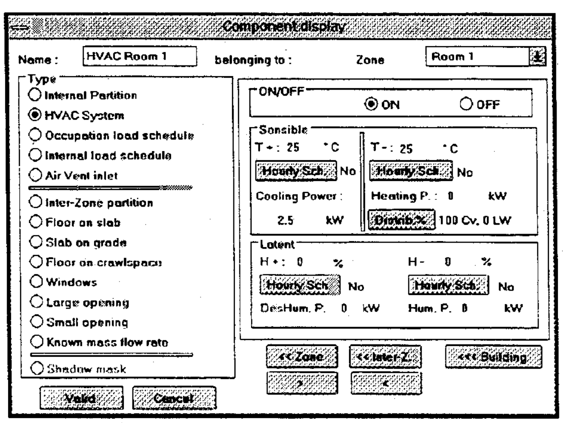

Fig. 13 : *HVAC system description window*

The components being of different types, specific information is needed for each component. Thus, for an air conditioning system, information relative to the sensible and latent loads are to be entered. We must then define the threshold temperature values (high and low), the hourly schedules and the available heating and cooling powers. Most of the time, simulation softwares consider the heating power as convective. However, to allow a better integration of systems such as heating floors, it is possible to choose for the involved power convective and radiative ratios. Another example of component window is concerning a partition wall.

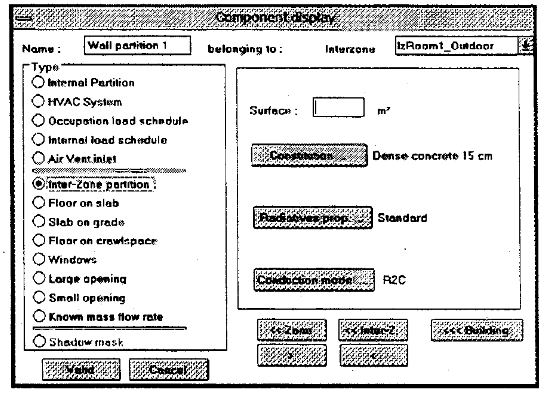

Fig. 14 : *Wall description window*

For such a component attached to an interzone, surface has to be entered, as constitution, radiative properties and conduction model. For these three last groups of information, default values are assumed (and mentioned). Action on the corresponding push-button give access to other windows allowing to change these default values.

FROM DESCRIPTION TO BUILDING MATHEMATICAL MODEL

As proposed by systemic analysis, we'll focus on one zone model constitution. With the usual physical assumptions, we use the technique of nodal discretisation ([Chapman 84], [Saulnier 85]) of the space variable by finite difference. In addition, the mass of air inside one zone is represented by a single thermal capacity. Thus, for a given zone, we'll consider the principle of energy conservation applied to each concerned wall and glass-window node. Then, associated with the sensible balance of the inside air volume and the radiative balance equation of inside radiant mean temperature, this set of equations constitutes the zone thermal model, that can be condensed in a matricial form :

$$[C]\left\{\frac{dT}{dt}\right\} = [A]\{T\} + \{B\}$$

In the previous equation, {T} is the vector of all the nodes of the zone and [C] is a diagonal matrix concerning their thermal capacities. [A] contains all the terms corresponding to energy exchanges in the considered zone and B contains sollicitations. Then, to build a multizone model, we consider the thermal coupling of sub-system zones (each having a matricial model), we solve each zone separately and assume temperatures convergence. The figure 10 shows the way of coupling two zones (1 and 2), their intersection constituting the Inter-zone [Blanc Sommereux 1980].

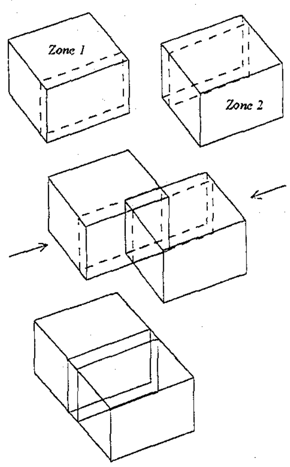

Fig. 15 : *Thermal coupling of two zones*

A given building is composed with a certain number of rooms, walls or also glass windows. From this variable description, the building splitting-up into a certain number of zones is a simulation parameter. Taking into account our sheme of iterative coupling between zones, our principal problem is one of the establishing of the state evolution equation of each zone, illustrated by next figure in the case of a two zones building.

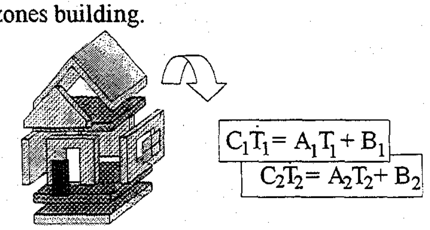

Fig. 16 : *From building description zones models*

To fill up each of those mathematical objets (i.e. C, A et B), from the description files of the building (walls, glass windows, ...), we build a data structure constituted of information fields attached to each discretisation node. An incremental number is attached to each node, to index our structure. The building description bringing in a certain number of walls and glass-windows, knowing the number of nodes constituting the discretisation of each entity, all the walls and glass-windows nodes can be numbered. Therefore, the building splitting up into thermal zones induces the setting of two nodes of temperature by zone (dry air and mean radiant temperature). The following figure explains our proceeding.

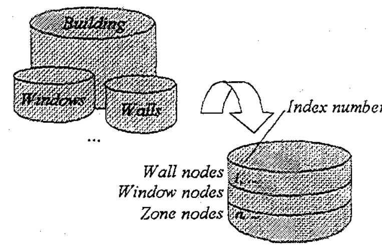

Fig. 17 : *The nodal structure generation*

A certain number of information fields are connected to a node, traducing for instance the appartenance of a node to a zone or also the topology of the global electrical network associated to the building. Considering the objective to be reached, we have been induced to impute a type to each node. Indeed, relatively to the equations, the nodes are concerned by different phenomenons. For instance, a wall node is going to concern terms of heat conduction. This same node, depending on its disposal, can also concern convective process. The board below gives in its first column the encountered types of nodes and in the second one a reference number that we'll find again on the next figure.

Type	*Ref. number*
Outdoor surfacic node of outside wall	*1*
Indoor surfacic node of outside wall	*2*
Internal node of outside wall	*3*
Outdoor surfacic node of outside glass-window	*4*
Indoor surfacic node of outside glass-window	*5*
Surfacic node of internal wall	*6*
Internal node of internal wall	*7*
Surfacic node of vertical interzone wall	*8*
Internal node of interzone wall	*9*
Surfacic node of ground wall	*10*
Internal node of ground wall	*11*
Terminal node of ground wall	*12*
Surfacic below node of horizontal interzone wall	*13*
Surfacic under node of horizontal interzone wall	*14*
Surfacic node of interzone glass-window	*15*
Dry indoor air temperature	*16*
Radiant mean temperature	*17*

On the building seen in cut of figure 18, we have only represented (with a white round) a few nodes of thermal discretisation. For these nodes, we've pointed out with a number sprung from the former board the corresponding type.

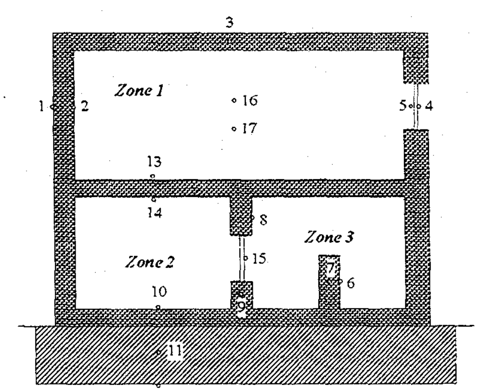

Fig. 18: Types of nodes.

For a given building, when this structure is established, it's easy to fill up each element of the mathematical model. Indeed, with a loop on the set of nodes, it's possible to test the appartenance of a node to the considered zone and, depending on its type, to affect the associated objets.

This paragraph makes explicit the method on the case of a simplified bizone bulding supposed without ceiling and floor and those view sketch in horizontal division is given in figure 19. The chosen conductive model in walls is of type 2RC (two surface nodes). The discretisation leads to arrange 18 temperature nodes in this building.

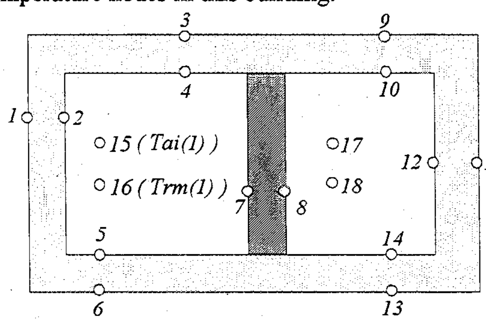

Fig. 19 : Simple two-zone building.

A zone model being defined as the sets of equations of the thermal balance of each node belonging to the zone, the state vector of the first zone is made of (T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_{15}, T_{16}), while the second zones concerns (T_7, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13}, T_{14}, T_{17}, T_{18}). We note that T_7 and T_8 are variables of each state vector, because the corresponding discretisation nodes belong two the recovery zone (hatched on the diagram). Then, each elementary system is of dimension 10.

For the first zone, an illustration of a part of the filling of the objets can be given. We'll take the example of heat conduction terms, constituting a matrix, A_{cond}. $K_{i,j}$ is designating the thermal conductance ($W.m^{-2}.K^{-1}$) between the nodes *i* and *j*.

$$A_{cond} = \begin{bmatrix} -K_{1,2} & K_{1,2} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ K_{1,2} & -K_{1,2} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -K_{3,4} & K_{3,4} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & K_{3,4} & -K_{3,4} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -K_{5,6} & K_{5,6} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & K_{5,6} & -K_{5,6} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -K_{7,8} & K_{7,8} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & K_{7,8} & -K_{7,8} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

In regard to indoor convection, to simplify the writing, we'll use a linear model with a constant exchange coefficient h_{ci} ($W.m^{-2}.K^{-1}$).

$$A_{cvi} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -h_{ci} & 0 & 0 & 0 & 0 & 0 & 0 & h_{ci} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -h_{ci} & 0 & 0 & 0 & 0 & h_{ci} & 0 \\ 0 & 0 & 0 & 0 & -h_{ci} & 0 & 0 & 0 & h_{ci} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -h_{ci} & 0 & h_{ci} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

ACKNOWLEDGEMENTS

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CONCLUSION

Establishing the level of approach of the building professionals, the first part applies the systemic analysis to the thermal design of buildings. The consequence of the splitting up of the building makes evident the sub-system thermal zone and lays the foundations of our description of a building. The data structures linked to the building turn on to be complex due to the diversity of the situations that can be described (the number of zones, the constitution of the covering of the building, the integration of systems, ...). Our focusing on the modelisation method and building description led us to introduce some description windows of our multizone software, *CODYRUN*. Many aspects developped to this day in this software have been purposely put aside, in particular in regard to as the multiple model innovator feature or airflow simulation. Meanwhile, for these points too, our work [Boyer 93b] shows the benefit of systemic analysis.

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