CLIM 2000 : THE BUILDING ENERGY SIMULATION TOOL AND THE MODELLING METHOD

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ABSTRACT

The rapid development in the thermal energy modelling requirements for buildings, marked by the need to integrate many phenomena, has led the Applications de l'Electricité department at Electricité de France to develop a general energy simulation tool called CLIM 2000.

Beyond the production of the software, our approach is to provide the specialists in the 7arious fields involved in the creation of the model library, with common formalisation rules ensuring clear and unambiguous expression of their work.

To do this, we have drawn up a method based on a thermodynamic approach to the phenomena. This leads from an analysis of the physical world to the definition of independent data processing modules subsequently installed in the CLIM 2000 software.

After presenting the main features of the CLIM 2000 software, we describe in this paper, the principles of the modelling method. The application of it is illustrated by an example: the air movement modelling in a building. In particular, we demonstrate its efficiency to facilitate the model design and the hypothesis management.

NOMENCLATURE

M = mass (kg)

U = intern energy (J)

C = specific heat capacity (J/K.kg)

C_v = specific heat capacity at constant volume (J/K.kg).

u = specific internal energy (J/kg)

uv = volume internal energy (J/m^3)

ρ ,ro = density (kg/m^3)

ϕ_U = energy flux (W)

ϕ_M = mass flux (m^3/s)

ρ_O, T_O = density and temperature references (kg/m^3, K)

W_i = power transmitted by electrical convector i (W)

M_m = molar mass (kg.mol^{-1})

W = external strength work (W)

R = ideal gas constant (8,314.JK^{-1}mol^{-1})

$\dot{m}_{ij}$ = mass flow from i to j (kg/s)

H_{ij} = enthalpic flow from i to j (W)

H_e, H_s = enthalpic flow through the air entry and through the air outflow (W)

$\dot{m}_e$, $\dot{m}_s$ = mass flow through the air entry and through the air outflow (kg/s).

P_{ext}, T_{ext} = external pressure and temperature (Pa, K).

1) INTRODUCTION

In order to deal with the rapidly evolving requirements in the field of building energy numerical simulation, the Applications de l'Electricité department of the Direction des Etudes et Recherches of Electricité de France decided in 1985 to develop a modular software called CLIM 2000.

It is a research tool aimed at a broad range of applications:

- detailed analysis of comfort and heat exchanges,
- development of control and building energy management systems,
- energy and financial evaluation of different projects,
- etc...

To achieve this objective, the concept of a model library and a ordinary differential equation solver was used as in other softwares such as TRNSYS [KLEIN 1981], HVACSIM$^+$ [CLARK 1985] ALLAN [JEANDEL and PALERO 1990], EKS/SPANK [BUHL et al. 1990] and IDA [SAHLIN 1988].

The CLIM 2000 software has been available since june 1989. From now on, the main task of its developpers is to fill its model library. Since very different phenomena are being involved in these models, several specialists have to participate in their development.

This task must not be overlooked. It is a capital item of the CLIM 2000 software in the same way as its data processing structure design. Indeed the software is useable only if it has a large library of compatible elementary models.

There, a modeling method has been developped. First of all, it defines three description levels each of them well suited with different coworkers: users, modelers and software developpers. It facilitates the elementary model design by a structured analysis of the involved phenomena. Lastly, it provides a highly precise framework called PROFORMA following the ideas of J. CLARK et al. [CLARKE and LARET] for the model description.

After presenting the main features of the CLIM 2000 software, we will describe in this paper, the principles of the modelling method. The application of it will be illustrated by an example: the air movement modelling in a building.

2) PRESENTATION OF THE CLIM 2000 SOFTWARE

2.1) A data processing architecture independent of the models

The principle of CLIM 2000 is based on a breakdown of the building and its equipment into independent elements (doors, windows, walls, heaters, etc...) the assembly of which determines thermal coupling or control. The overall energy behaviour of the building and its equipment is thus the result of this assembly.

In modelling terms, each element is the subject of a Basic Model, and the building fitted with its various items of equipment is called the Global Model (see figure 1).

Numerically speaking, a Global Model is a set of algebraic and differential equations solved using the ASTEC software [HEYDEMANN 1981]. This is based on a variable order and step GEAR algorithm for the integration of differential equations and a NEWTON-RAPHSON method for searching for the roots of algebraic equations. Its high performance allows global simulation of the coupling of heavy building structures and faster response phenomena or systems.

This architecture thus separates the data processing structure of the software from the basic models in its library. Moreover, the performance of its numerical solver offers the users a broad range of dynamic simulation options.

The data processing functions of the CLIM 2000 software are:

- handling and storage of basic models,

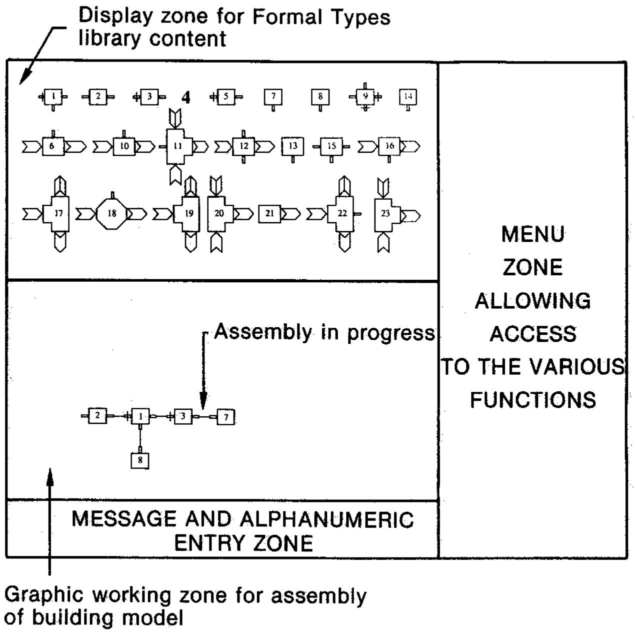


Figure 1 – Diagram of the CLIM 2000 software entry screen [RONGERE 1990].

- provision and assembly of these basic models as needed by the user for a given study,
- creation of a system of differential equations resulting from this assembly,
- solving of this system to give the evolution of the state of the building covered by the study,
- display of the results obtained,
- CLIM 2000 also handles the management of the studies conducted.

2.2) A high-level data structure associated with the basic model: the Formal Type

For CLIM 2000, a basic model is not a simple calculation procedure, but comprises all the information needed for its handling and installation in the software. It is thus represented by a complex data processing structure called the Formal Type.
A Formal Type consists of a schematic representation, or icon, enabling it to be identified by the user, a mathematical representation corresponding to the equations associated with it, supplemented by the various initialisation processing and preliminary calculation operations, an alphanumerical representation defining the parameters to be supplied by the user, and the accessible results, and a control representation in the form of connection rules used to check the validity of the assembly produced by the user.
The communication interface of this data structure is represented by connection ports. These can comprise one or more associated

values or correspond to a particular model:

- identity of state variables and sum of associated fluxes,
- energy transfer through mass transfer,
- collection of information,
- etc...

(see figure n° 2).

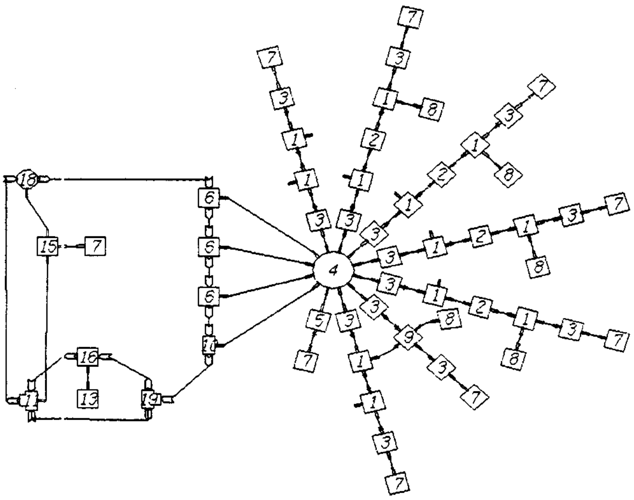


Figure 2 – Assembly representing a single-zone building model for the CLIM 2000 software. [RONGERE 1990].

2.3) A user-friendly interface, and tools to simplify the data entry

2.3.1) Assembly of "Formal Type" occurrences: macro type

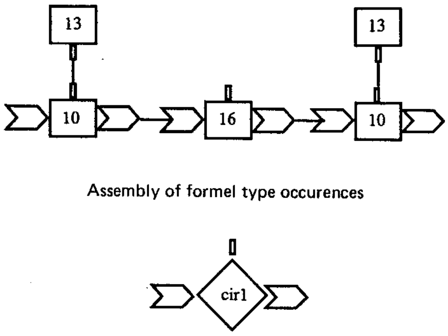
Following the principle of CLIM 2000, the user produces a global energy model of the building by creating and assembling different "Formal Type" occurrences available in the library. These occurrences inherit properties of the "Formal Types" from which they are taken, in particular the default values associated with their numerical parameters.

This assembly is made easier by an additional tool called the Macro Type. This allows memorisation of an assembly of "Formal Type" occurrences, which can then be handled like a new basic model (see figure 3), and can be exported to other studies, or made accessible to other users by means of the data base management system.

Apart from the graphic facilities, the "Macro Type" allows the management of collections of assemblies and sets of numerical parameters. It will thus be possible to create libraries of insulating materials and HVAC systems.

2.3.2) Simulation and results analysis tools

CLIM 2000 also has a results display



Assembly of formel type occurences

Equivalent macro type

Figure 3 – Macro type.

module offering a broad range of features:

- comparison of calculation results and experimental measurements,
- complementary calculations on these results,
- various graphic formats (curve, histogram, pie chart, etc...),

(see figure 4).

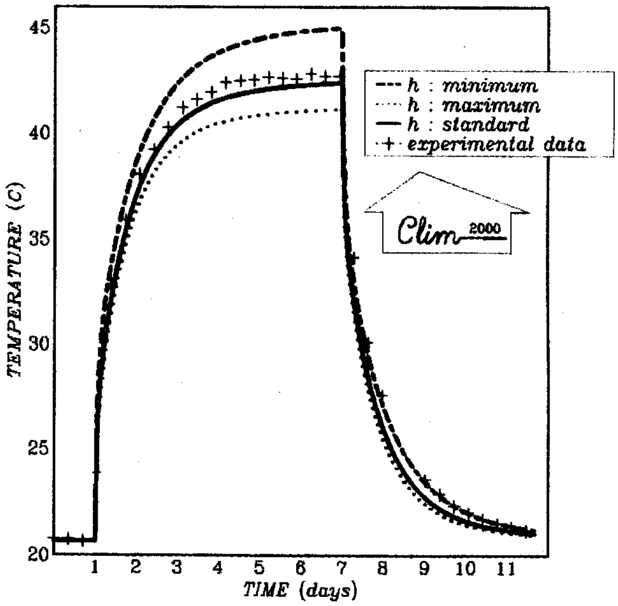


Figure 4 – Comparison between experimental and numerical results (ETNA laboratory). [GIRAULT et al. 1990].

3) MODELLING METHODOLOGY

3.1) Why a modelling method ?

Independantly of the quality of its data processing structure the CLIM 2000 software will be realy used only if the elementary models of its library are well described and compatible. The design and the formalisation of these models are major tasks.

The first problem to be solved is then the definition of the elementary model concept. This is different for:

- the project engineers (or users) who use the elementary models like black boxes,

- the modelers who realize the elementary models,

- the software developers who code the elementary models in the CLIM 2000 software and manage the equations to be solved.

For the project engineer dealing with a global building model, a basic model is a technological component of the building or its heating and air conditioning equipment: a convector, a hot water tank, a window, etc.

For the modeller however, a basic model is a more abstract notion. His objective is to represent the energy-related behaviour of an item of equipment, or "Technological Component". He thus concerns himself with the physical phenomena involved, seen through a number of assumptions. Hence, for the modeller, basic models idealise representations of physical phenomena. He classifies them, not according to technological criteria, but rather according to their physical properties: i.e a part of the system on which a balance is drawn up, a local behaviour law within a material, the expression of a transfer of energy or mass, etc...

From the viewpoint of the developper, who handles the mathematical equations to be solved, a basic model is a data processing object which has methods. These methods need to be organised in order to create the solving process.

Moreover, the means of assembling these basic models is not the same for the three partners defined above. For the user, the connection of two basic models consists in technological connections:

- joining of two pipes,
- opening of a window in a wall,
- etc.

For the modeller, the assembly of two basic models is, for example, the location of a transfer between two parts of a system.

Finally, for the developper, the connection of two basic models is the same as identifying several occurrences of the same value or, in certain cases, in adding them to make a balance.

It is thus plain that a single level of representation is not sufficient to ensure effective management of the basic model libraries in an open-ended software such as CLIM 2000.

Strict formalisation and the connection of the three levels of representation described above are, in the CLIM 2000 project, dealt with by means of an original modelling method. The main principles are presented below, along with an illustration of how it is used.

3.2) Principles of the modelling method

Note: The modelling method firstly concerns the designers of models (modellers). It then bridges the gap between their viewpoint and that of the users and the software developers.

To achieve this, we first of all introduced three levels of representation:

- the TECHNOLOGICAL COMPONENT, for the user,

- the BASIC MODEL, for the modeller,

- the MODULE, for the developper.

Following the principles of thermodynamic analysis, we defined three notions:

- the ELEMENT, which constitutes a portion of the system to be studied, on which the balances are to be drawn up,

- the MATERIAL which, on the basis of the ELEMENT state values, gives access to the measurable variables which will determine the TRANSFERS,

- the TRANSFERS which link the ELEMENTS and give the values of the fluxes intervening in the balance equations.

The figure n° 5 summarizes this approach [RONGERE 1989]. It should in particular be noted that the balance equations are expressed on the extensive system state variables (masse, energy, etc...) and not directly on the measurable variables, as in the other approaches such as the nodal method or Bond Graphs. This distinction allows a stricter formalisation of the problems by separating the extensive geometrical aspects from the local properties linked to the materials constituting the system to be studied (see below § 3.3).

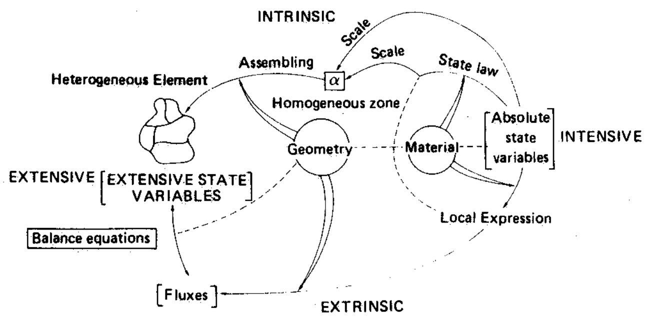


Figure 5 – Schematic decomposition of a model. [RONGERE 1989].

Furthermore, within the framework of this method, we defined a modelling problem analysis method which naturally leads the modeller, from the global level, corresponding to the TECHNOLOGICAL COMPONENT of the project engineer, to the description of the MODULES to be handled by the numerical equations solver system (see figure 6). This analysis mode (top-down) thus completes the assembly features (bottom-up) offered by the library et MODULES, BASIC MODULES or TECHNOLOGICAL COMPONENTS.

• PHASE 0 :

General analysis of the problem.
→ Breakdown of TECHNOLOGICAL COMPONENTS into ELEMENTS.

• PHASE 1 :

Breakdown of ELEMENTS into HOMOGENEOUS ZONES :
→ Choice of EXTENSIVE STATE VARIABLES.
→ Breakdown of the element into ZONES.
→ Definition of the laws of ASSEMBLY on STATES and FLUXES.
→ Définition of GEOMETRICAL laws.

• PHASE 2 :

Transition from EXTENSIVE VARIABLES to INTENSIVE VARIABLES of each ZONE.
→ Choice of the SCALE.
→ Calculation of INTENSIVE STATE VARIABLES.

• PHASE 3 :

Choice of MATERIAL constituting the ZONES.
→ Establishment of STATE EQUATIONS.

• PHASE 4 :

Check on CONSTITUENT resolution CONSTRAINTS

1st step : MATERIAL and STATE EQUATION
OK → move to step 2.
NO → return to phase 3 then phase 2.

2nd step : SCALE
Constant SCALE → move to step 3.
Variable SCALE → add SCALE as EXTENSIVE STATE VARIABLE of ZONE.

3rd step : GEOMETRY and ASSEMBLY
OK → move to phase 5.
NO → return to phase 2 then phase 1.

• PHASE 5 :

Choice of LOADINGS and INFORMATION ON THE STATES and INFORMATION ON THE FLUXES.

• PHASE 6 :

Check on RELATIONAL solving CONSTRAINTS.

1st step : MATERIAL CONSTRAINTS
OK → move to step 2.
NO → return to phase 3 or phase 5.

2nd step : GEOMETRY CONSTRAINTS
OK → move to phase 3.
NO → return to phase 2 or phase 5 then phase 1.

3rd step : Sequential organization of INFORMATION
OK → coherent model → END (write objective description of new TECHNOLOGICAL COMPONENTS, MODELS and MODULES).
NO → return to phase 5.

Figure 6 – Main phase of model construction [RONGERE 1989].

Finally, the semantic definitions attached to each category of BASIC MODEL, allow them to be automatically handled and thus limit the parameters to be supplied by the modeller.

3.3) Example of aerodynamics modelling of a two room dwelling

We concern ourselves with the modelling of aerodynamic exchanges between the rooms in the same building, subject to variable meteorological conditions. For this, the problem is considered as the exchanges between two rooms communicating via a large vertical opening (figure 7).

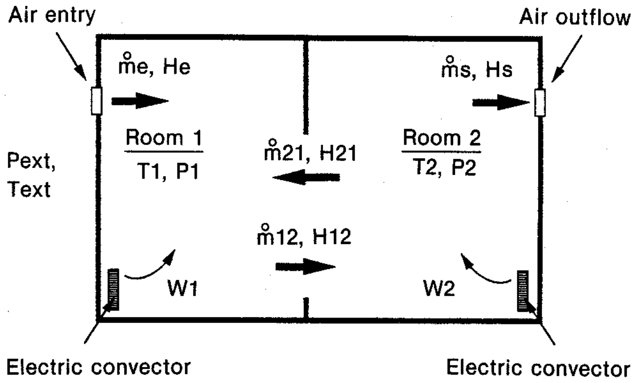


Figure 7 – Ventilation in a two room building.

We consider that the air behaves as a ideal gas and that each room consists of a single homogeneous air zone, of uniform temperature and subject to hydrostatic pressure. The flowrates between zones are governed by the Bernoulli equation. The systematic analysis proposed for the method leads to the breakdown of the problem as shown in figure 8.

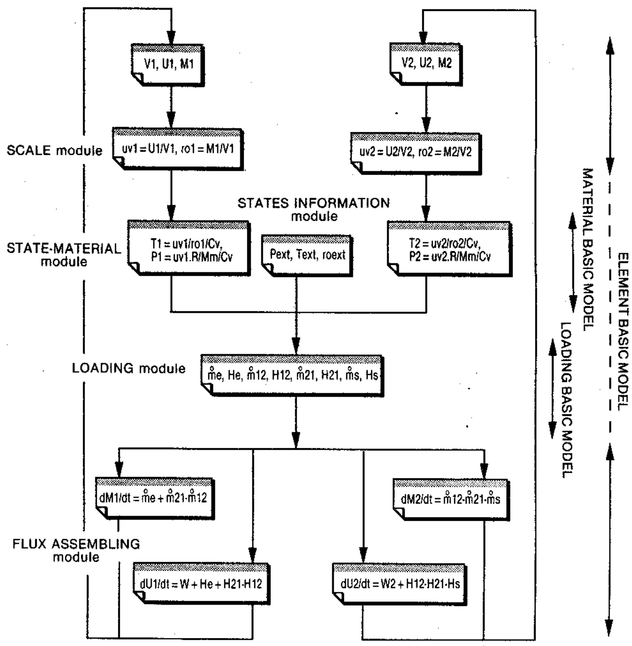


Figure 8 – Diagram of methological breakdown for the two room building problem.

We can see a succession of procedural tasks which will constitute the various MODULES implemented by the developper.

For the modeller, the BASIC MODELS created are:

- the air in the zone: ELEMENT model,
- the vertical opening: TRANSFER model,
- the ideal gas material: MATERIAL model.

Following this analysis, we thus obtain independant BASIC MODELS documented in the form of PROFORMA sheets, and which can be used in other configurations.

3.4) Discussion on the aerodynamic transfer assumptions

With this method, the balance equations are naturally written for the extensive state variables (Energy and Mass). Then the "scale step" leads to the expression of the local values of these variables. (Volumic energy and Volumic Mass) (see figure 5).

At this stage, no assumptions are formulated about the gas state law. This may be modelized independantly.

The left column of the figure 9, presents two different gas models. These models are expressed in an extensive variable form according to our method. The first one (top) is the ideal gas model, it uses two state variables. The second one (bottom) is the incompressible gas model: the state of the gas is independant of the pressure. The pressure equation desappears in the MATERIAL model. This leads to the energy balance equation suppression.

The right column of the figure 9, gives the intensive expression of these models. We can see that their manipulation may be uneasy due to their unlinear forms.

Now, let us compare these models with the conventional formulation (figure 9, right column bottom model). It's assumptions (constant mass and incompressible gas) are not compatible.

In fact, this uncorrect formulation has no consequences in conventional global building energy simulation since the differential terms of the air balance equations are negligible compared with wall inertia. In addition one use to maintain the room temperature stable. In any way, it would be better to write the following algebraic equations:

$$0 = \Sigma\phi_u$$

$$0 = \Sigma\phi_M$$

On the opposite when one focus on a fast evolution of the air state, one has to take account of these differential terms. From the balance equations related to the ideal gas model (see figure 8), we can deduce the

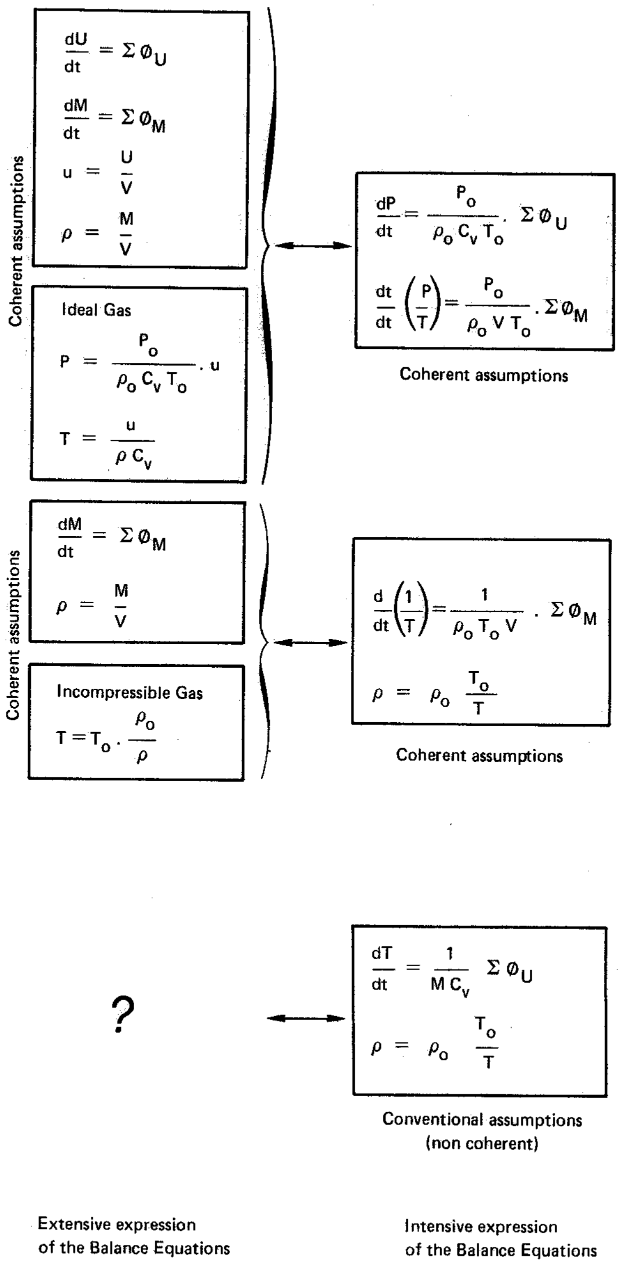


Figure 9 – Comparison between two air balance equation formulations.

following expressions for small pressure and temperature deviations:

$$\frac{\Delta M}{M} = \frac{\Delta P}{P} - \frac{\Delta T}{T}$$

$$\frac{\Delta U}{U} = \frac{\Delta P}{P}$$

Hence, if $\Delta P \simeq 1000$ Pa then $\frac{\Delta U}{U}$ # 10^{-2} and in addition, if $\Delta T \simeq 3°C$ then $\frac{\Delta M}{M}$ # 2.10^{-2}.

4) CONCLUSION

In accordance with its purpose, the CLIM 2000 software enables the researchers and the designers to make building energy simulation by assembling elementary models available in its library.

Its data processing structure strictly separate the equation solver and the building model. Hence it is an efficient numerical tool to perform many different simulations. In addition it is able to manage new elementary models as soon as they are developped.

Since the CLIM 2000 software has been achieved, we have now to ensure the quality of the model library growing. This challenge is major in our opinion, and we split it in three main tasks:

- providing to the CLIM 2000 users, usable elementary models,

- to defining an efficient description PROFORMA in order to facilitate the model management and the compatibility controls,

- avoiding redundant elementary model developments.

The modeling method used in the CLIM 2000 project meets these requirements. Its main features are:

- three representation levels, each of them, well suited with the user, the modeller and the developper points of view,

- a structured design methodology to classify phenomena and hypothesis occuring at every step of the model analysis,

- a description formalism called PROFORMA.

The example, presented in this paper, illustrates the efficiency of this approach to facilitate the model design and the hypothesis management. In particular, we easily demonstrated by this way that the conventional asumptions used for air movement in building modelling (i.e: the room air mass is constant) are not rigorous ; this especially when the volumic mass is supposed to be proportional with the inverse of temperature.

In fact, the errors induced by these asumptions are negligible in a global energy consumption computation. On the other hand, they may be important in detailed air movement calculations which are being developped nowadays.

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