# CLIM 2000: MODULAR SOFTWARE FOR ENERGY SIMULATION IN BUILDINGS

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*ABSTRACT :*

*The CLIM 2000 software environment was developed by the Electricity Applications in Buildings Branch of the French utility company, Electricité de France. This software, which has been operational since June 1989, allows the behaviour of a whole building to be simulated. The building is described by means of a graphics editor providing multi-windowed dialogue in the form of a set oficons representing the models chosen by the user These models are taken from a library containing about one hundred elementary models supplied on a standard basis by the software. Furthermore, the software's modular structure means that new models can be developed quickly and made available to users.*

*Four years' experience operating CLIM 2000 confirms the advantage of the model assembly approach in defining and in solving a building thermal problem. This experience is an encouragement to continue increasing the software's potential in response to users' requirements and according to the disciplines involved. Indeed, certain users favour a technological approach to describe a problem before making their modelling choice. This approach is the aim of an upgrading project for the CLIM 2000 preprocessor, to be completed for 1995. While retaining the possibility of conducting studies by assembling models, this will also allow the technological description of a building by means of geometric views of its frame and principle diagrams of its equipment.*

*After explaining how to conduct a study using the current version of CUM 2000, we state the problems to be solved in preparing the software's future version.*

## 1. INTRODUCTION

Numerous experimental investigations aimed at mastering the energy-related behaviour of buildings and its equipment are being conducted by the Electricity Applications in Buildings Branch, a section of the Design and Research Division of Electricité de France. These investigations are, however, proving difficult and costly, and sometimes even unfeasible, in the case of the study of complex building configurations. Digital simulation are, therefore, also being used.

The studies carried out on buildings have, moreover, changed considerably over the last 15 years. The modelling of heat transfers (conduction, convection and radiation) was all that was needed to cater for the main requirements of studies conducted during the 1980's. The studies performed today are more demanding. They entail the analysis of the occupant's comfort, the comparison of different heating or ventilation systems and the pertinence of a complex control system, and they cover buildings in the residential, service and industrial sectors. These studies all require global analysis of the energy-related behaviour of the building's frame along with their equipment (heating, ventilation and air-conditioning systems,...) and the modelling of complex phenomena such as air flows between rooms, temperature stratification inside rooms,...

An open-ended software package capable of working on the new models developed thus became indispensable. Existing software packages produced at the beginning of the 1970's, including the CLIM package created by the Electricity Applications Branch, did not respond to these requirements satisfactorily. Consequently, design work on the CLIM 2000 software, started in 1985, was based on the model library and the general algebraic differential equation solver concepts also used in other software packages such as TRNSYS (Klein 1981), HVACSIM+ (Clark 1985), ALLAN (Jeandel and Palero 1990), EKS/ SPANK (Bhul and Co. 1990) and IDA (Sahlin 1988).

After becoming operational in June 1989, the CLIM 2000 software was enriched with new models as the need arouse so that it covered a vast range of applications. A constant effort was made to continue developing the software structure. This led to the launching of a new version of the software package (2.0) in December 1992, equipped with a data entry tool providing multi-windowed dialogue based on a Relational and Graphics Database Management System and on the X-WINDOW and OSF/MOTIF libraries.

After a brief description of the modelling principle adopted, we propose to illustrate how a study is conducted with CLIM 2000. We will then give details on the upgrading approach for the CLIM 2000 data entry module currently being developed. This process is aimed at providing a more efficient response to the needs of users who prefer preparing a technological description of the building before they start modelling. Essentially, this involves creating a user interface allowing the geometric data on the building's frame to be entered in conjunction with principle diagrams of its equipment, without detracting from the efficiency of the CLIM 2000 modules principle.

## 2. THE MODELLING APPROACH UNDER CLIM 2000

### 2.1 Modelling principle

Modelling is performed on the basis of the supposition that the building's global behaviour is the result of the assembly of elementary models representing the dynamic behaviour of the components of the building's frame (walls, doors, windows, ...) and the components of its equipment (heating appliance, hydraulic system pipes and valves, ventilation ducts and openings, control equipment,...) (Rongere 1989).

The complexity of the model assembly varies widely according to the type of study. The model assembly obviously differs depending on whether the study concerns the energy balance for a whole building or the comfort of an occupant in one room. The choice of models is, in fact, left to the study manager who will choose the most suitable model for each of the building's components or groups of components, which are referred to as technological components. The choice of each model is governed by numerous criteria: physical phenomena taken into account, model accuracy, computing time,....

### 2.2 Putting modelling principle into practice in CLIM 2000 software

#### *2.2.1 How are elementary models implemented?*

Each elementary model is implemented in CLIM 2000 in the form of a computerized data structure, referred to as the Formal Type.

A Formal Type includes:

- a diagrammatic representation, or icon, so that it can be identified and manipulated by a graphics editor,

- a mathematical representation corresponding to the equations describing the dynamic behaviour of the technological component modelled,

- an alphanumeric data structure defining the variables for the equation solver and the accessible results.

Each Formal Type is also provided with a fixed or variable number of link tabs (see the example in Figure 1) allowing its assembly with other Formal Types.

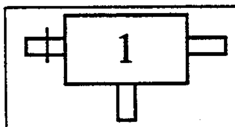

Figure 1 - Icon representation of a Formal Type . Example.

Each link tab is characterized according to a predefined multiple-criteria classification (Covalet 1992). A series of criteria is assigned to each link tab (see Tables 1,2 and 3). A link declared between two tabs linking two models is checked by verifying the compatibility of the series of criteria assigned to each link tab. It will be seen hereinafter (see § 2.3.1.3) that the checking tool is capable of detecting and indicating various types of incompatibility. It is then up to the user to make the necessary corrections or carry on regardless.

| Table 1 - Type class for a link tab | Table 2 - Exchanged physical variable by a link tab (more than one possible for a type class) |
|---|---|
| THERMAL | TEMPERATURE |
| ENTHALPIC | THERMIC FLOW |
| THERMIC AND ENTHALPIC | ENTHALPIC FLOW |
| HYDRAULIC WITHOUT CHARGE LOST | DELIVERY WITHOUT CHARGE LOST |
| AERAULIC | AIR PRESSURE |
| AEROTHERMIC | AIR PERTAINING TO THE MASS FLOW |
| INFORMATION WITHOUT DIMENSION | TEMPERATURE |
| AIR TEMPERATURE | DELIVERY |
| WATER TEMPERATURE | BIG LENGTH WAVE FLOW |
| AIR DELIVERY | COMMAND VOLTAGE |
| WATER DELIVERY | POWER |
| BIG LENGTH WAVE FLOW | RADIANCE |
| COMMAND VOLTAGE | RELATIVE HUMIDITY |
| POWER | WATER PERTAINING TO THE MASS FLOW |
| RADIANCE | |
| HUMIDITY | |

| Table 3- Exchanged feature (one by exchanged physical variable) | |
|---|---|
| IMPOSED | PROPAGATED |
| RECEIVED | INDIFFERENT |

#### *2.2.2 The hierarchically-organized library of standard-supply Formal Types*

About 100 elementary models are currently provided as standard supply by the software. Each model has a corresponding descriptive form specifying its characteristics (icon, equations, variables to be entered, accessible results) and all the details required for its choice (modelling hypotheses) and optimum use (utilization limits, recommendations, ...). Each form can be consulted from under the software.

All the models are supplied in a hierarchically-organized library displayed on the screen in the form of a tree structure with headings and sub-headings corresponding to the description of the technological components modelled and with "terminal sheets" corresponding to the models available (see Figure 2 on next page).

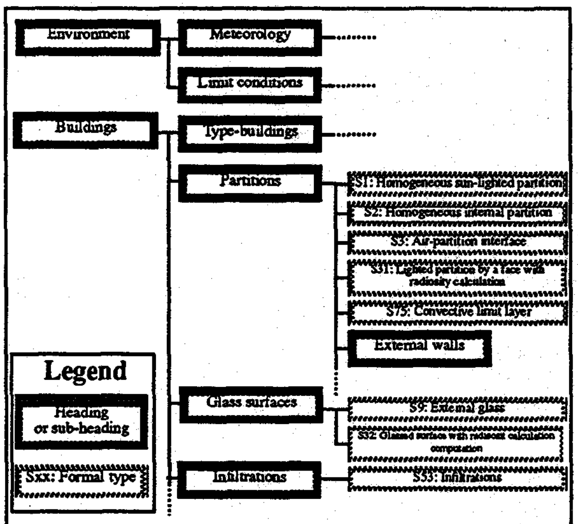


Figure 2 - Extract of the standard-supply library of Formal Types

*2.2.3 The advantages of a relational and graphics database management system*

All the information required to manipulate the Formal Types is managed by a Relational and Graphics Database Management System around which the CLIM 2000 data entry module is built. The experience gained through four years in operation shows that a system of this type offers many advantages:

- Highly sophisticated organization of the information needed for a study. This extremely rich structure requires no modification when new Formal Types are added. It guarantees the upgradability of the CLIM 2000 Model library.

- Optimization of data volumes. A study comprising several hundred Formal Type Occurrences corresponds to a database of only about 2 Mbytes.

- Quick access to the various sets of values facilitated by the organization of data tables (see Figure 4 on next page).

- Display and dynamic manipulation of the icon assembly graph remaining consistent with the database contents at all times whatever action the user takes.

- ...

## 2.3 Using CLIM 2000 for parametric simulations

*2.3.1 Describing the building to be studied with the graphic icon assembly tool*

Once the Formal Types required to model the building's frame with its equipment are available, the acquisition of the problem consists in assembling all the selected Formal Types and filling in their characteristic parameters. The user then selects the results to be worked on.

The assembly operations are performed using the CLIM 2000 graphic interactive data entry interface (Bonneau 1992). This interface allows the Formal Types to be manipulated directly by their icons (see Figure 5 on next page). The Formal Types taken from the library are supplied with default values.

Among many other functions, the data entry interface can be used to duplicate Formal Type Occurrences assigned with customized values in the graph. In addition, to lighten the task of entering numeric values and reduce the risks of error, the tool also proposes data entry windows of the spreadsheet type so that all the characteristic parameters for Formal Type Occurrences of the same kind can be entered in one go.

### 2.3.1.1 Manipulating Formal Type assemblies: concept of Composite Type

The task of constructing assemblies is facilitated by manipulating Composite Types (see Figure 3) which contain assemblies of Formal Type Occurrences and/or Composite Types that have already been filled out. The Composite Types are stored in the library and can be manipulated in the same way as Formal Types. Any Composite Type can be reused a number of times in the graph for one study, used in other studies or communicated to other users.

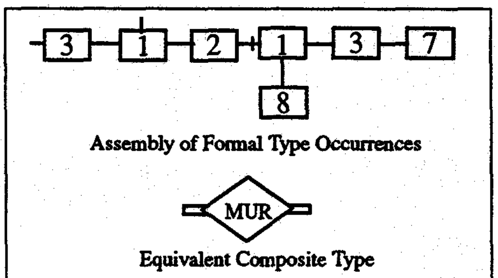


Figure 3 - Composite Type

### 2.3.1.2 Preparing simulations for a parametric analysis

Once the building's global model has been constructed, it is possible to prepare:

- several sets of values for the numeric parameters of Formal Type Occurrences,

- several sets of parameter values describing the building's meteorological situation and simulation conditions (simulation period, result recovery time step, ...),

- several sets of result selections,

- finally, several sets of parameters for setting the algebraic differential equation solver which will provide the numeric solution to the problem.

Submission to the solver is preceded by a selection phase to define a set of each type for a simulation. All the sets of values used for a simulation are saved in their current state so that they can be used again later. The sets of values for a reference simulation previously conducted can be recovered and modified to carry out an efficient comparative analysis.

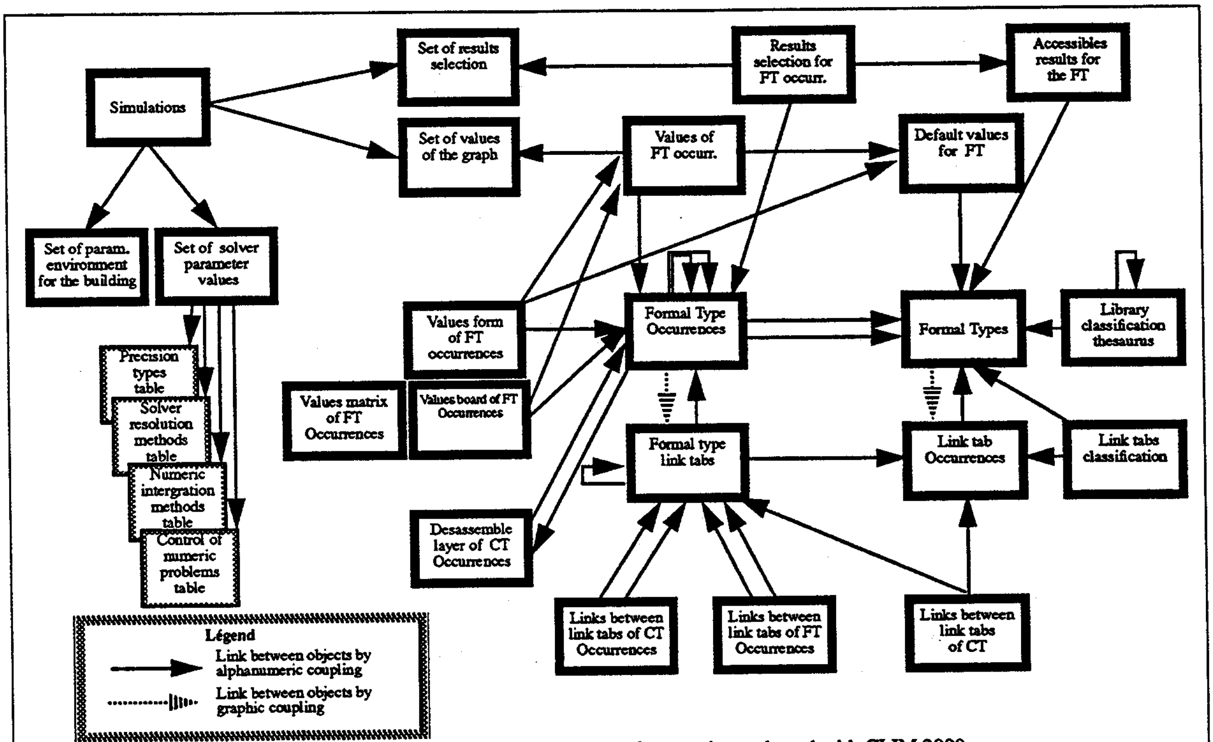


Figure 4 - Organization of a database for a study conducted with CLIM 2000

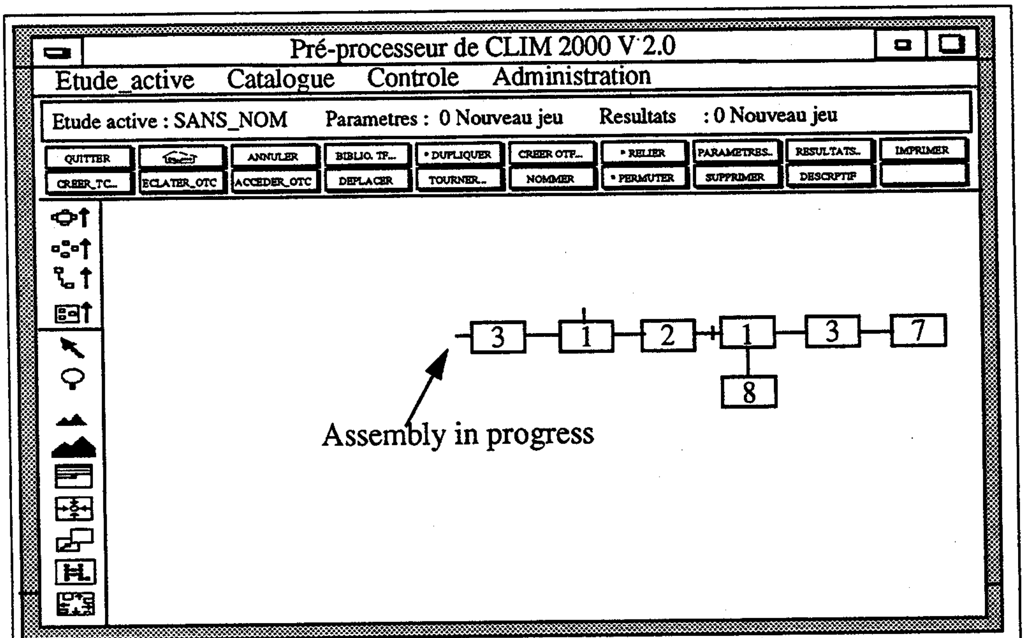


Figure 5 - The CLIM 2000 data entry window

2.3.1.3 Checking the consistency of numeric parameters for Formal Types and links

There are two check levels before a simulation is actually started:

- Check on numeric parameters: The numeric values for each Formal Type Occurrence must be consistent with the field of definition. All defective Occurrences are highlighted in the graph.

- Check on links: According to the classification of link tabs (see § 2.2.1), the tool checking the validity of links between Formal Type Occurrences detects any incorrect links and indicates two types of error in the graph, as follows.

- The link is classified as PROHIBITED (see Figure 6) when it links two tabs that are mathematically incompatible.

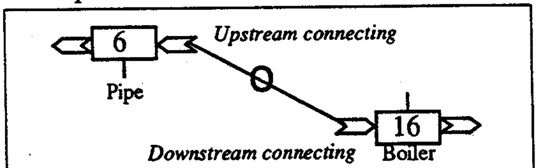


Figure 6 Indication of a PROHIBITED link

- The link is classified as DEGRADED (see Figure 7) when the tabs carry magnitudes that are numerically compatible but their link has no physical justification.

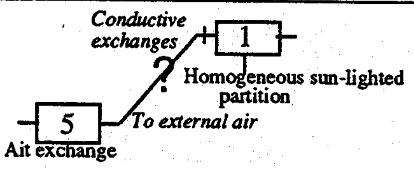


Figure 7 Indication of a DEGRADED link

In the case of defective links, the user is free to make the necessary corrections or to force the simulation to go ahead.

It is also possible to carry out checks on all or part of the graph during its construction.

### 2.3.2 Analyzing the results

Once the numeric solution has been obtained, the CLIM 2000 postprocessor module (see Figure 8) proposes a wide range of functions to analyze the results:

- calculation of complementary results by combining the simulation results in equations,
- comparison between experimental measurements and simulation results,
- formatting of results in various forms (curves, histograms,....).

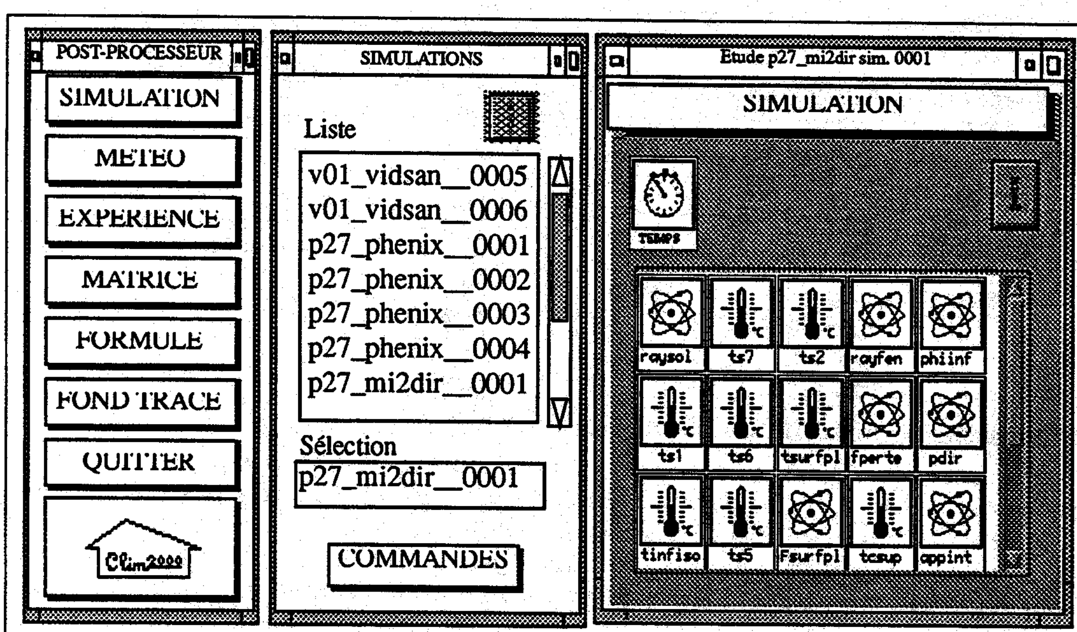


Figure 8 - Preparatory windows for the formatting of CLIM 2000 results

## 3. UPGRADING OF THE CLIM 2000 USER INTERFACE FOR DIALOGUE SUITED TO THE VARIOUS DISCIPLINES

We saw in section 2 that for the acquisition of a problem, the CLIM 2000 user interface relies on the assembly of Formal Types. The experience gained in the use of this software bears out the advantage of this modular approach. It also encourages us to extend its scope to include the manipulation of components represented by their geometric forms for the building's frame and principle diagrams of its equipment.

Indeed, the acquisition of studies by directly assembling model representations does prove to be rather abstract. Although it is attractive to model designers, it is less suitable for other users. The latter adopt a technological approach to the problem and, therefore, require a more realistic view of the building. This involves a new concept, a user interface with various layers one on top of the other, each having a specific function (heating, control,...).

### 3.1 Acquiring the geometry of the building's frame by assembling 3D figures

The dynamic modelling of the building involves only the building's general geometric data and not the geometric shapes of its components. This means that the building can be equated to a sum of parallelepiped shapes for the rooms and prismatic shapes for the roof.

This tendency was confirmed to members of the CLIM 2000 users club by mockup work on the user interface (see Figure 9 on next page) for the geometric acquisition of the frame of buildings studied. In addition, the mockup proved to be totally efficient in characterizing the frame of a building by assembling 3D figures.

This approach allows the geometry of parts and the overall topology of the building's frame to be defined quickly. The volume of rooms, the positioning of walls and their dimensions are deduced very directly. Acquisition is performed on the basis of 2D views of the building's frame with at least one top view and one side view. A 3D view displayed on request allows a quick visual check on the geometry and topology.

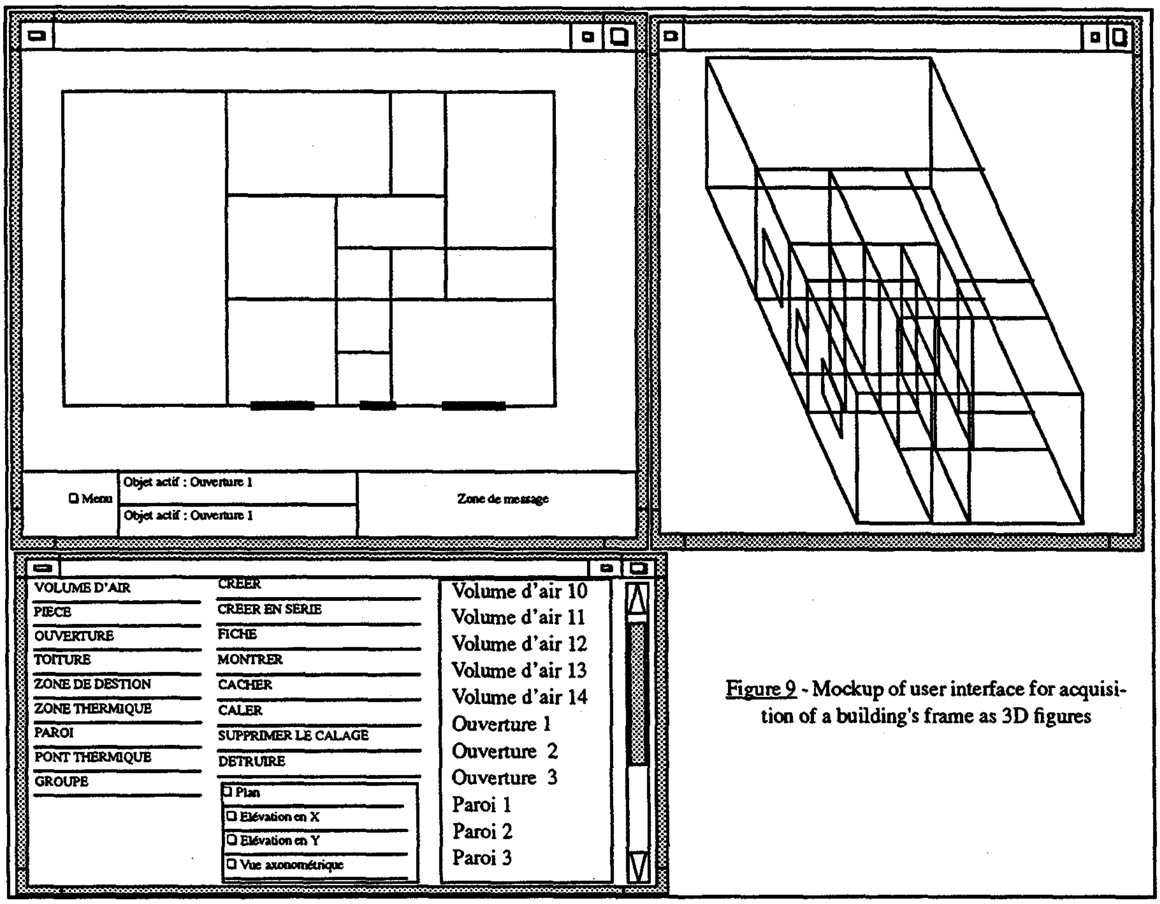


Figure 9 - Mockup of user interface for acquisition of a building's frame as 3D figures

The description of the frame is then completed by the positioning of openings in the walls. These openings are liable to be fitted with closing systems (doors, windows, ventilation openings,...). The modelling of the building's frame is then started by defining thermal areas. A thermal area is the assembly of contiguous rooms on which the user bases the hypothesis of homogeneous and uniform thermodynamic variables (inside temperature, humidity,...). The modelling process undertakes to simulate energy transfers between the various thermal areas via the exchange surfaces constituted by the walls between areas.

## 3.2 Acquisition of system principle diagrams

The complexity of each system (heating, air-conditioning, domestic hot water production, control,...) is often apprehended by users by means of non-dimensional principle diagrams. The diagrams show:

- appliances (heating outlet appliances, heat pumps,...).
- devices (valves, circulating pumps,...),
- links between appliances or devices (pipes, ducts,...),
- information sensors (temperature probe, flow meter, hygrometer,...),
- channels conveying information from sensors to appliances or devices.

The functions provided by the current CLIM 2000 data entry tool show themselves to be well suited to defining the principle diagram of a system. The graphic view handling facilities of this tool must, however, be enhanced in order to manage more than one diagram simultaneously and define the necessary links between different diagrammatic views of more than one system. In addition, they must allow the technological components of equipment to be carried over onto geometric views of the building's frame.

## 3.3 Coupling up system principle diagrams wtih building geometry

The graphic coupling of views of the building's frame with diagrammatic views of equipment will involve only certain technological components. Indeed, the graphic precision with which these components are located in the building's frame will depend on the geometric data required by the corresponding models. The various locations to be envisaged for these components in a given thermal area are as follows:

- simple indication that the appliance appertains to the thermal area (presence of a heating outlet appliance in the area with modelling of convection phenomena only),
- specification of the appliance's position (1D, 2D or 3D coordinates of a point: for the location of an information sensor, for example),
- the positioning of the appliance's surface area

occupation in the thermal area (modelling of radiation phenomena),

- positioning of the appliance's volume occupation in the thermal area (modelling of temperature stratification phenomena in the room).

### 3.4 Ensuring the link between the building's full description and models

It is mandatory that the geometric description of the building's frame and the principle diagrams of its equipment should be unambiguously converted into a determined assembly of elementary Model Occurrences (as the solver accepts only this form).

Consequently, a model is associated with at least one manipulated technological component. Several elementary models or assemblies of elementary models (Composite Types) may be available for a single technological component. The presentation of elementary model assemblies may contain:

- a predetermined assembly,

- an assembly calculated on the basis of the characteristic time of the phenomena to be observed in the technological component. (For example: the number of elementary models concerning phenomena of conduction through a layer of homogeneous material inside a wall depends on the thermal characteristics of the material and the thickness of the layer).

It is important that all these cases should be taken into account and that the user interface should propose efficient dialogue tools, especially for the entry of data for the models contained in assemblies without the user requiring the details of the assembly.

## 4. CONCLUSION

The CLIM 2000 software package, based on the model library and general solver concept, accepts new models with no problem. In its current version, it provides an extremely user-friendly graphic tool to describe the building to be studied in the form of an icon assembly graph representing the models. Each model is capable of simulating the behaviour of a component or an assembly of components of the building's frame or equipment. The model library, provided as standard supply by the software, can be enriched according to user requirements. Equipped with about one hundred models, it covers a vast range of applications.

Four years' experience operating CLIM 2000 confirms the advantage of the model assembly approach in defining and in solving a building thermal problem. This approach is well suited to model designers but proves rather abstract for users who prefer preparing a technological description of the building before they start to choose their modelling. In response to the needs of users who favour a technological approach allowing them to describe a problem before making their modelling choice, a CLIM 2000 preprocessor upgrading project was started in 1992 and is to be completed for 1995. While retaining the possibility of conducting studies by assembling models, this will also allow the technological description of a building by means of geometric views of its frame and principle diagrams of its equipment.

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