THE SIMULATION OF LARGE SCALE INTERCONNECTED SYSTEMS FOR BUILDING AND EQUIPMENT PERFORMANCE EVALUATION

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ABSTRACT

Presently, the building performance analysis requires to take accuratly into account the coupling effects between building, HVAC and control. For large scale systems, this implies the intensive use of the simulation tools.

Today, the existing tools are not flexible enough for this purpose. The present paper describes the development of a more adequate tool : CSTBât. This tool is built on the TRNSYS core (University of Madison), but offers a more adapted library of solvers and component models concerning the building envelope and the hot water heating network. These developments are based on a very powerful and generic base of models, allowing different levels of analyses from very simple to very detailed. The model parameters are directly issued from the standard characteristics.

The software structure extensively uses hierarchical and modular principles and a user interface gives the possibility of a natural description of complex systems. The present tool was developed at the CSTB in the frame of a cooperative action with Gaz de France for the detailed analysis of a large viariety of heating systems.

I INTRODUCTION

The design and the management of the present building equipment requires intensive detailed analyses, and the simulation becomes the only way to get enough information. The level of requirements and the complexity presently reached for the energy management in the buildings place this sector in the same position as other industrial activities, for instance, process plant, aerospace,... Moreover, the energy performance analysis of a whole building including the corresponding HVAC system cannot be performed independently from the other aspects such as comfort, day lighting, costs, and on a larger scale the energy production efficiency. Thus, an integrative dimension is naturally introduced to the traditional specific view on energy analysis, and the recent developments of computers allow the use of rather powerful simulation environments. However, different phases are required between the system description and the performance analysis, and each phase requires different types of high level expertise.

The Figure 1 shows the main phases :

- modelling : which means the mathematical formulation of the physical system, where the knowledge comes from physics,
- simulation algorithm : where the numerical solving techniques are used in order to build a numerical processing ; the knowledge comes from the mathematics by the numerical analysis.
- software code : where the previous models, solving techniques and data managers are joined in a given tool, using the software engineering techniques.

This paper briefly describes these different steps and the user interface for a given tool, CSTBât, oriented to the energy analysis of building and HVAC systems.

2 MODELLING

Large scale systems cannot be solved directly as a whole. Different levels of decomposition followed by the resulting aggregation have to be considered.

The modelling of complex systems is a very good example of this process. At least, in our applications, a first decomposition is rather natural : the building envelope, the surrounding climate, the heating (or cooling) equipments, split into heat generation and distribution.

However, the decomposition into basic components cannot be made without taking into account the future coupling. The model choice is directly dependent of the future applications. Moreover, the different analyses to be carried out, imply different scales of models, from very detailed to very simple, and a minimum coherence between the model input, output and parameter should be maintained. Thus, the design of well suited or adapted models is essential [2]. These models are based on a physical formulation of heat transfer dynamics. The resulting choice is a state space formulation expressing the energy conservation in dynamic conditions where the potential is the temperature. This gives a generic formulation following finite element principles :

$$X\dot{T}_1 + Y_A T_1 + Y_B T_2 = Y_{OA} T_{OU} + Q_A$$

$$Y_C T_1 + Y_D T_2 = Y_{OB} T_{OU} + Q_B$$

where X is a diagonal matrix of positive terms expressing the thermal storing, Y_A, Y_B, Y_C, Y_D, Y_{OA}, Y_{OB} are matrices expressing node thermal connection,
T_1 and T_2 are nodes of storing and non-storing elements, respectively, T_{OU} external boundary conditions of potential, Q_A and Q_B boundary conditions of heat flows.
The energy and mass conservation principles imply some constraints on the parameters. This very basic form can represent very detailed meshing as well as very rough models, such as building second order models. For the building models, different rules have been defined in order to produce different level of analyses [3] [4]. The resulting models are very powerful and are more and more used, especially for building energy management system analyses (see for instance Annex 17 of the International Energy Agency : dynamic simplified building model).

Following the same tracks, the other pieces of the system can be modelled, including all the non-linearities of the HVAC components. Thus, boiler simple models were designed [6], and the whole heating network has to consider the water mass flow computation. At this level, a simple representation of the hydraulic behaviour was designed in a linear form :

$$Y_H P = \dot{M}_S$$

where P is the pressure at the different network nodes, $\dot{M}_S$, the effect of hydraulic active components, Y_H , a friction matrix of the pressure flow component models. For complete close systems, the computed pressure may only consider the pressure drop only due to the friction terms. In most analyses, the corresponding decomposition of absolute pressure into its gravity and friction term avoid the introduction of complex topological information.

To summarize, the network model links hydraulic and thermal models following a nodal view at hydraulic and thermal level, using generic models able to reach detailed or simple representation. The building models allow also simple and detailed thermal analysis. The connection between these macro elements and the control system is direct.

All these formulations can also be introduced in several solving environments and constitute a sound basis of well suited models for large scale analysis. It should also be highlighted that the model parameters are directly obtained from the standard characteristics.

3 NUMERICAL ALGORITHMS

The whole system appears on the scheme of Figure 2, and the main links are indicated. The general techniques, commonly used by the general solvers are not the most appropriate in this case. Two extreme principles can be applied : pure iterative or global solving. Pure iterative methods are the most efficient when very convergent schemes are possible. Global methods are the most appropriate when the system is symetrically and equally connected as for the thermal transfer inside the enveloppe.

Thus, global techniques are used for the building enveloppe. The method is based on the analytical solutions of the state space equations, using the matrix functions, in this case combinations of matrix exponential [3]. The exponential of matrix are computed by the corresponding development in series. This is the simplest way for unsymetrical matrices. The unsymetry results from the oriented air flows by infiltration or by ventilation. The hydraulic network is solved directly by the inversion of the friction matrix. Presently, this matrix is taken constant and obtained by linear approximation of the hydraulic characteristics. The inversion technique is the Gauss elimination based on the maximum pivot on line and on column. The system is always well conditioned and the process does'nt show any particular problem. The method could be very easily generalized for non-linear characteristics, using the Gauss-Newton iterative technique, also always convergent for physical characteristics. The thermal model of the hot water network is solved following the water flows. The network loops are solved by iterative techniques based on substitution methods using the secant (or Aitken) algorithms.

The same iterative process is used in order to link the different macro-components : building enveloppe and network pieces (boiler and loopless sub-network pieces).

4 SOFTWARE DESIGN

The simulation tool was developed in FORTRAN 77 around the TRNSYS basis, adding a totally portable library of new types and general services library. But only macro-components are appearing as TYPE.

So, TYPE 50 is the generic building model, TYPE 45 the hydraulic network computation, TYPE 49 a loopless piece of the network for solving the thermal behaviour, different TYPES offer different boiler model levels and combinations. All these macro-components are built with a hierarchy of basic components, including their links, as it can be seen on Figure 3. It means rather complex data structures. A library of matrix modules, and corresponding solving techniques based on matrix functions, allow efficient solutions of linear differential systems.

However, for true scale applications, all the connected elements imply a huge amount of data. For this reason, a better user interface was designed. With the interface, only the minimal information is required, a lot of coherence checks are introduced, and the component characteristics are obtained from catalogs. The user has only to refer to the name of a piece in the catalog. Also the network description is very generic. This gives a very dense and clear typed formalism. Figure 4 gives a short overview of the entities processed by the interface in connection with the component catalog. It should also be pointed out that the interface could also be linked to other solvers able to calculate the generic models proposed in the CSTBât library.

5 CONCLUSION

Using the TRNSYS core, by the addition of the CSTBât library, large scale simulations including building envelope and hot water heating systems are possible. A user interface allows a very natural description of all the concerned entities by the link with components catalogs.

The modelling base allows the analysis at different scales of complex interconnected systems. All the model parameters are directly linked with the standard data. The different models are in validation at Gaz de France, by comparison with the experimental data of different configurations of hot water heating systems in a full scale experimental building [1].

The model base could also be used in other solving environments and is a rather complete coherent set for large scale analysis.

6 REFERENCES

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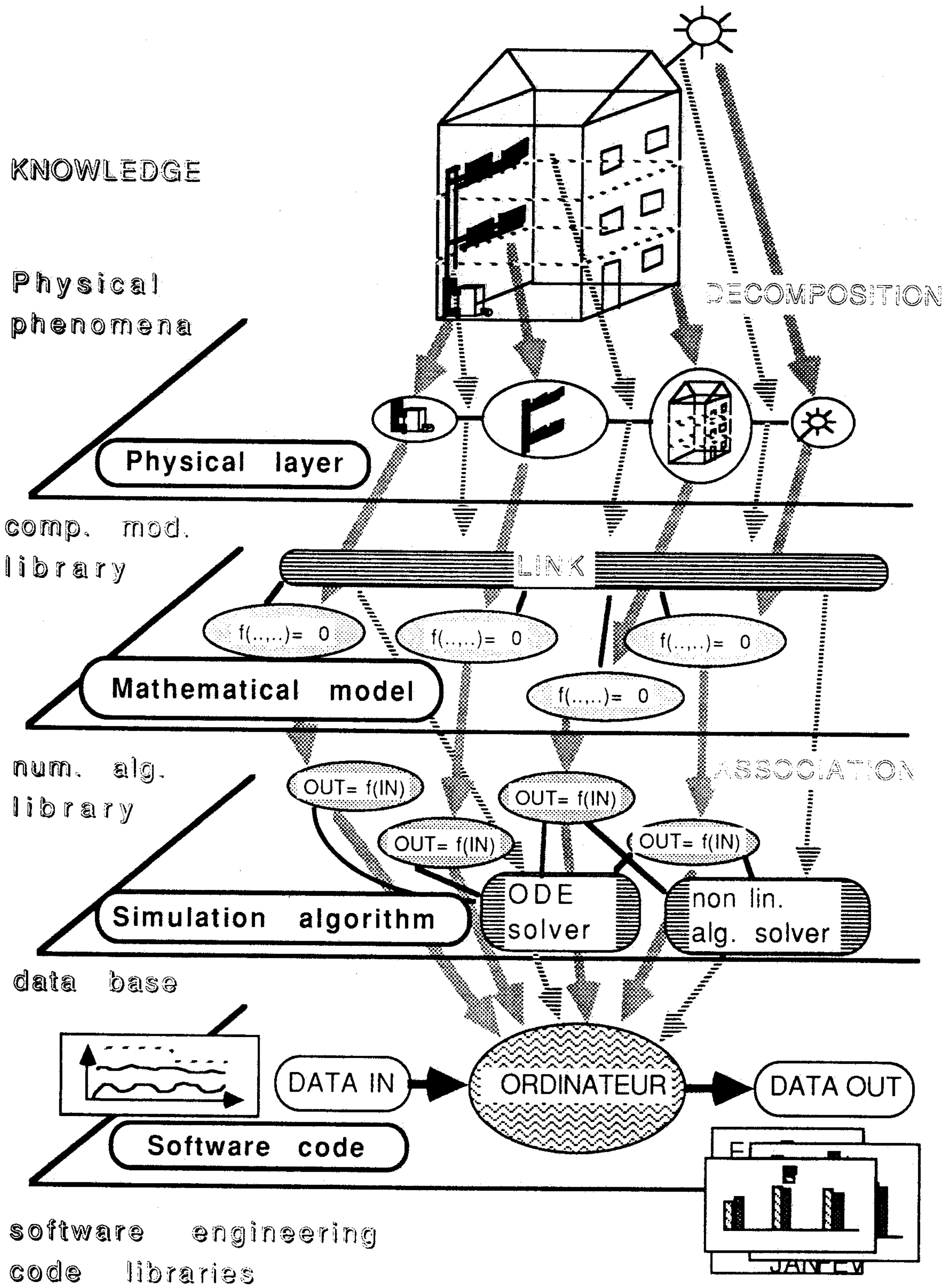

Figure 1.-The different steps from building and equipment to the simulation tool.

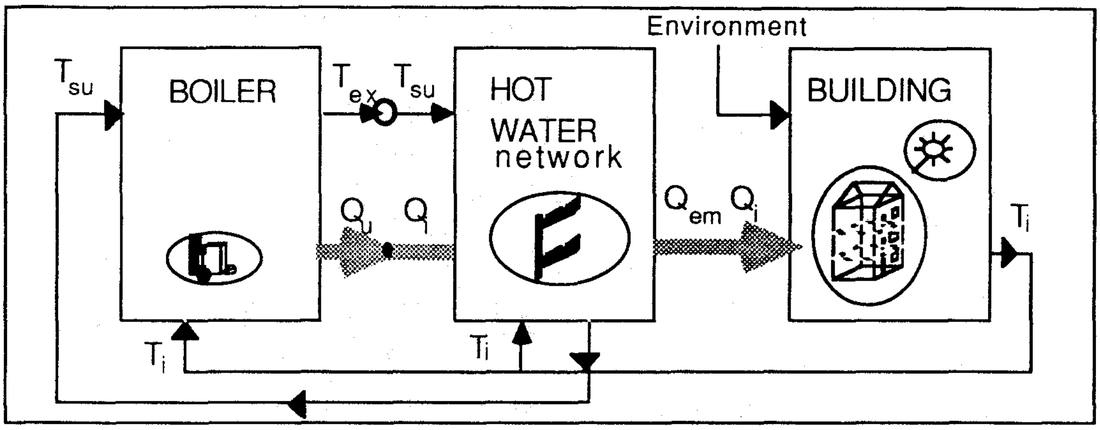

Figure 2.- Principle of modelling and simulation of the building and heating system. Main entities and connections.

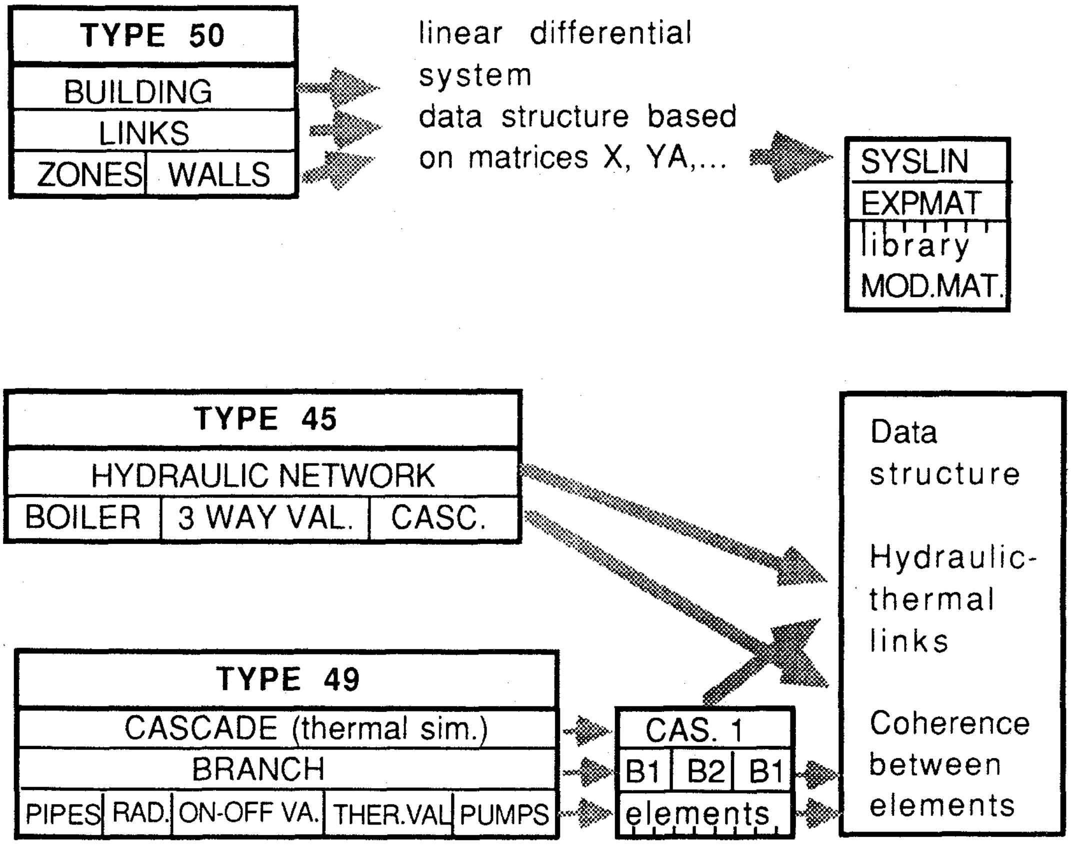

Figure 3.- Hierarchical design of the CSTBât software modules based on different levels of entities. Hypermodularity of the software.

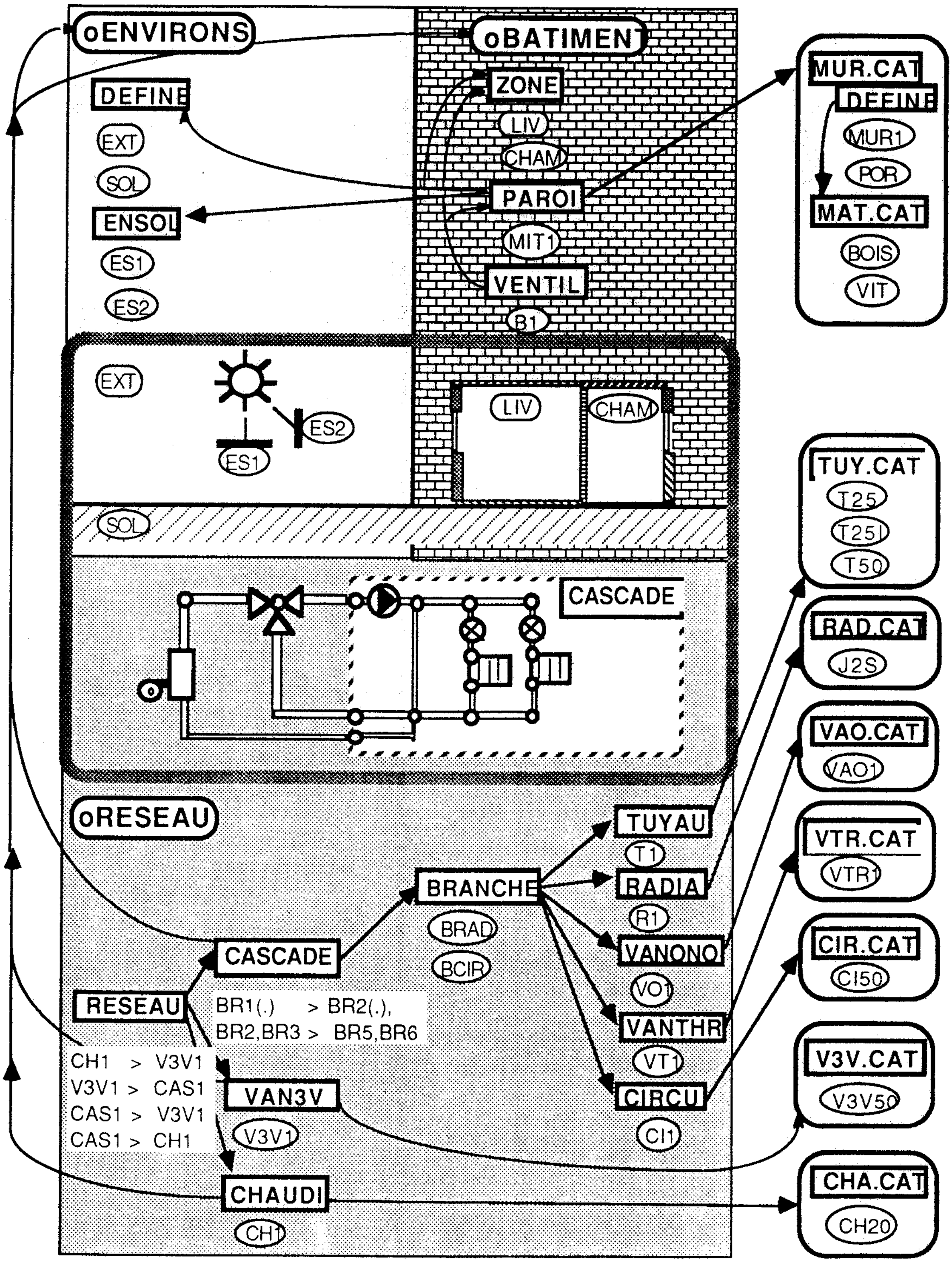

Figure 4.- Scheme of entities used in the interface of CSTBât and connection with component catalogs.