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THERMAL MODELLING AND SIMULATION OF BUILDINGS AT GAZ DE FRANCE

Alexandre JEANDEL and Isabelle PALERO

GAZ DE FRANCE
Research and Development Division - DETN
Gas Utilization Research Center - CERUG
361, avenue du Président Wilson
F-93211 LA PLAINE SAINT DENIS CEDEX
FRANCE

Abstract :

The approach adopted by the Gaz de France Research Centre for the modelling-simulation of building performance separates as far as possible modelling from simulation.

Modelling, which here signifies the mathematical representation of the phenomena under study, involves the creation of a model library, independent of the simulation tools, comprised of PROFORMA forms. These models are characterized above all by their state of validation.

Simulations may be performed using specialized software such as CSTBât/TRYNSYS and ALLAN.SIMULATION/NEPTUNIX.

This approach, the aim of which is to make optimum use of the models and simulation tools, is being tested on two studies. The first concerns the operating strategy for a boiler plant in a commercial building and the second concerns individual hot water central heating control. This work is being conducted in parallel on CSTBât and ALLAN, with joint use of certain models.

Apart from the concrete results of these studies, we are particularly interested in determining the validity of our approach and we hope that many useful lessons will be learnt.

1. INTRODUCTION

In the fast developing field of domestic heating systems, GAZ DE FRANCE provides effective scientific and technical backup to its various industrial partners. Research and development work on building energetics is being extended. Two investigation methods are used in parallel : full scale testing and numerical simulation. The GAZ DE FRANCE test facilities have been fully described in a number of presentations which are well worth reading [1,2]. Here we are more specifically interested in numerical simulation.

2. SIMULATION NEEDS AT GAZ DE FRANCE

A simulation is an artificial representation of a real behaviour. For numerical simulation, the model equations are converted into a computer programme by means of a numerical algorithm. Many such programmes exist at GAZ DE FRANCE : ALLAN/NEPTUNIX [3,4], CSTBât/TRNSYS [5,6],RIGEL [7] or BILGA [8] to name but a few.

The objectives of the GAZ DE FRANCE Research and Development Division as regards residential and commercial space heating evolved following the first energy crisis in the 1970's. However, priorities change and new legislation covering insulation of new dwellings, which came into force on 1st January 1989, has set for a certain time to come the requirements in terms of performance. When assessing different systems, the criterion of comfort in terms of "quality" is now a factor as important as that of energy performance.

The role of simulation

Simulation may be useful to reproduce tests, and thus aid in their comprehension, to extend the range of these tests on the system under study or to change certain characteristics.

Understanding phenomena through modelling may be a means to acquire new knowledge. This is the task of the modeller

The exploitation of models validated by simulation adds an additional dimension to tests, either by providing a guide for subsequent action or by giving extrapolation opportunities. It may be useful as an aid to the design of new systems. This is the task of the simulation software user.

Technical objectives

The technical objectives of studies involving simulation are as follows :

- to understand phenomena,
- to size equipment,
- to validate control systems,
- to calculate energy loads.

The simulation results obtained for fixed systems under standard reference excitations are evaluated according to criteria of quality, comfort and consumption.

These objectives govern the choice of models to be adopted.

Desired work methods

The requirements of the industrial world oblige us to aim towards a work method combining low cost, rapidity and quality.

Simulation is only one means, alongside testing, for achieving specific technical objectives. The head of any study must be able, if he so wishes, to have access to an aid to the definition of expected simulation results, to a library of models adapted to his needs and to effective simulation tools. In particular, simulation may aid him to define tests and extrapolate them. The models must be adapted to the questions posed and reliable (or, more exactly, must have a known degree of reliability). The expertise contained in simulation tools thus makes it possible to overcome technical and physical problems and provide a concrete answer to the question in hand.

Once the study has been clearly defined, the operating principle chosen separates as far as possible modelling from simulation, so that the efforts of each member of the research team are concentrated in his own field of competence (physics, computing or numerical analysis) and so that stepping stones between these fields are created and recognized as such.

The task is thus broken down into three stages :

- Definitions of the problem and of the expected simulation results
- Modelling (choice of models, creation and validation of other models)
- Simulation (choice of the simulation tool and simulations)

This mode of operation must be put to the test in the daily reality of the company. The methods employed to this end are presented here. This paper is thus a presentation of the methods used and the procedures adopted to implement them.

3. DEFINITION OF THE PROBLEM

The problem definition phase is necessary to obtain an accurate estimation of the resources needed, of the work to be undertaken and hence the feasibility of the study. The aim is to transform the general objectives of a study into a list of phenomena to be taken into account, of simulations to be performed and criteria to be respected. The criteria and phenomena to be taken into account govern the choice of model and simulation software.

This result can only be obtained through dialogue and through the and experience of those involved.

4 MODELLING

Model creation

Modelling is the choice and formulation of mathematical equations which are solved to provide information on the phenomena under study. This choice depends totally on the technical objectives defined at the outset and is of vital importance in ensuring the success of the study. It is therefore necessary to adopt a systematic modelling approach to ensure that the right choices are made.

This approach involves three levels of analysis :

Technical morphological analysis : what are the different components of the system ? In our field of activity, they may be walls, air zones, heaters, control systems, etc...

Physical analysis : for each of the components chosen in the first phase, what are the phenomena involved, those which will enable us to meet the GAZ DE FRANCE study objectives ? What are the physical variables which couple with other components

Choice of the mathematical representation of these phenomena by means of algebro-differential or logical equations containing characteristic parameters of the components and the variables required for coupling with other components.

The approach proposed by François Xavier RONGERE [9] of Electricité de France may provide a help in making these analyses.

We will deliberately stop here. If we moved on to the next stage, involving numerical and computer formulation of the mathematical representation chosen, we would lose the ability to make use of such models in all the various simulation tools at our disposition. We will therefore stay at this level, the final product being a PROFORMA form.

The PROFORMA model library

At GAZ DE FRANCE, the PROFORMA model library is not computerized. It is a collection of PROFORMA forms. A paper giving the history of the forms, the exact description of their headings and their management has been written by the authors of the concept [10, 11,12]. The PROFORMA form plays several roles, and should not be seen as limited to its purely documentary aspect.

The form design is the result of a minimum consensus between numerous research teams on what constitutes a model and hence, implicitly, on what approach should be adopted to create it. It helps the form user to ask himself the right questions, and he is all the more conscious of this if in his first attempt at modelling he tried to do without the forms. This is the most important point.

The form is also an excellent means to transfer knowledge from the creator of a model to a third person. Anyone who has ever tried to make use of someone else's model will understand the advantage of a complete and unique model format.

It is a collective memory of the various specialists who have, at some time or other, worked on thermal models of buildings.

5. MODEL VALIDATION

But what is the worth of a PROFORMA form which has not been validated ? Obviously... it is no more than a potentiality, unable to satisfy the operating objectives described above.

Nevertheless, the validation method chosen is not limited to experimental validation only, but includes four types of validation qualified as numerical, analytical, qualitative and experimental. They act upon different worlds. Figure 1 gives a classification of these worlds, showing the action of each of these types of validation.

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Numerical validation

Defined as the comparison of simulation results of a single model run on two different programmes. In fact, it is only able to bring into question the computer implementation or the numerical method of the software. We use it to compare simulation software.

Analytical simulation

Defined as the comparison of simulation results with a particular solution calculated by hand or using a specific programme. It provides the transfer between the modelled world and the numerical world.

Qualitative validation

Defined as the comparison of simulation results with the modeller's mental picture of reality. It is used to ensure that we have really modelled what we intended to model. This stage is considered vital at GAZ DE FRANCE and is formalized in tables of standard excitations which must be filled in. It is the only validation possible for equipment design.

Experimental validation

Defined as the comparison of simulation results with the same physical quantities observed experimentally in the laboratory at full scale. It is the only validation which is able, in parallel with qualitative validation, to provide a formal and quantified validation of a set of measured excitations, and thus a controlled extrapolation of the field of validity of the model. The quality of a model of an existing object is judged during experimental validation. For this type of validation, specific test procedures must be drawn up.

These forms of validation may apply to each of the models taken separately then, as the complexity of the study increases, to coupled systems. All contribute to the quality of the model.

By placing these different validation methods in parallel, the nature of the problems encountered can be determined and the necessary skills mobilized. The tranfer from "reality" and the "measured" world is the job of the experimenters. The tranfer from the imaginary to the modelled world is the job of the modeller. It is up to the numerical analyst, and the computer specialists to reach the simulated world.

Our objective is to ensure the transfer to the modelled world by means of an appropriate modelling method. When the objects under study exist in reality, we start out from the "measured" world, when we wish to design new objects, we start out from the imaginary world. The evaluation of simulation tools concerns, among other things, their capacity to complete the full path towards the "simulated world".

We place ourselves from the outset in the role of the modeller and the simulation tool user.

6. SIMULATION

The tools available

Models must be used in simulation to be validated. GAZ DE FRANCE possesses several simulation programmes, whose names are given above. Only two are sufficiently general and modular to be suitable as a simulation tool independent of modelling. They are CSTBât/TRNSYS and ALLAN.SIMULATION/NEPTUNIX. They are described briefly below.

CSTBât/TRNSYS

The environment used to model the experimental building is CSTBât, based on TRNSYS. TRNSYS was developed at the Solar Energy Laboratory of the University of Wisconsin in Madison and marketed in 1975.

TRNSYS is a modular system simulation software to study transient systems. It is written in FORTRAN and is flexible to use as each entity to be modelled is individualized and integrated into the whole under the title of "component" New components must be added to study new problems. They may be written in FORTRAN or any other compatible language.

CSTBât includes an interface for input of the construction characteristics of the complete energy system under study, a library of advanced components of thermal building performance and numerical techniques. Gaz de France's exclusive version accepts high performance models for large scale thermal simulation. These models were developed by the french Scientific and Technical Center for the Building Industry CSTB [5,6] as part of a research contract and are currently being validated by GAZ DE FRANCE.

figure 2

Its modular structure makes it very flexible. The physical problem of the building subjected to the environment and to its heating equipment, with or without control systems, is thus broken down into a library of models.

figure 3

These models and techniques may be exported to other, so-called new generation computer environments at low cost.

Conversely, models described in the PROFORMA forms may be introduced into the CSTBât/TRNSYS environment after transcription into computer language.

ALLAN.SIMULATION/NEPTUNIX

figure 4

ALLAN [3,4] is a programme designed at the Systems Analysis Department of the GAZ DE FRANCE Research and Development Division and developed with the aid of CISI Ingenierie, which is also marketing the product. ALLAN is a preprocessor and not a simulation software. It is used at GAZ DE FRANCE in its current version to describe models for the NEPTUNIX 2 simulation program [13]. It may also be used with ASTEC 3.

The results of the approach presented enable us to describe simple models with ALLAN which have two representations : an internal representation (the equations of the PROFORMA form) and an external representation (a graphic symbol with input and output terminals to which other models can be linked). By associating simple models graphically, compound models can be created which can in turn be used to create other models. The relations between the models take account of the dimensions of the physical variables handled.

The preprocessor provides the simulation sofware with the complete problem to be solved in an appropriate form and handles the graphic processing of simulation results. This latter part is also used for the results of other software such as CSTBât.

The tool separates modelling as far as possible from simulation, leaving the authors fully responsible for their models while relieving them of the tasks of computer programming and numerical techniques implementations. It is therefore highly suited to the working approach presented here.

Evaluation of simulation tools.

The two tools will be fully operational in 1991.

CSTBât is in its final development stage. To ensure that its results are fully reliable, the model coupling phase may be tested again.

ALLAN.SIMULATION/NEPTUNIX has been on the market for more than a year (since april 1989) but, as it is very general, it is supplied without any models. A library of thermal building performance models has been implemented under ALLAN and is being validated. We may consider that validation work is able to ignore the transfers between the modelled and simulated worlds, as this is handled by the tool.

We must ensure that these tools will enable us to concentrate on our modelling and simulation activities.

To provide a full understanding of the two tools and the approach presented here, two studies have been chosen for full scale evaluation of the approach and the tools. They are presented below.

STUDY 1

This first study deals with the **operating strategy of a boiler plant for a commercial building** [14]

Before explaining the context, we should note that this study extends well beyond the scope of simulation tool evaluation.

New or renovated non-residential buildings are increasingly being equipped with natural gas-fired collective boiler plants. These may include, for example a combination of condensing boilers and standard boilers and a set of hot water radiators. The performance of this type of heat production system depends greatly on operating conditions, namely the installation power requirements and management of boiler operation.

The objective is to assess a set of criteria (relative comfort, consumption) for given simulation scenarios, with two heat production management methods, each associated with a particular type of natural gas heating management.

The hot water space heating installation with boiler plant and heating management is presented on figure 5.

figure 5

We will see whether our tools are able to meet a part of this objective for the case of a simplified model of a commercial building comprising a finely modelled combined boiler plant.

STUDY 2

The definition of study 2 is complementary to that of study 1. It concerns **the comparison of individual hot water central heating control systems** with a fine building model.

The objective is to compare the simulation results of the different control systems with given excitations for a set of criteria of comfort and consumption :

* Non-modulated on/off control thermostat on fixed output boiler associated with thermostatic valves
* Non-modulated on/off control thermostat on boiler with adjustable water temperature associated with thermostatic valves
* Proportional modulated on/off control thermostat on fixed output boiler associated with thermostatic valves
* Proportional plus integral on/off control thermostat on fixed output boiler associated with thermostatic valves
* Modulated on/off control thermostat with elimination of static error on fixed output boiler associated with thermostatic valves
* Progressive action thermostat on modulating boiler associated with thermostatic valves
* DIANE control system [15]
* Temperature regulation at boiler outlet to a set value calculated according to outside temperature on individual on/off control boiler

The figure below represents the internal ALLAN representation of one of the cases treated.

figure 6

As in study 1, the parallel implementation of all the models in the two programmes and their simulations enables us to judge the ability of each to handle the problem in hand.

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Software choice

The first comparison between the programmes arises from the content of their libraries, since though the models concern the same objects, they are not identical. The availability of a model, ease of creation will inevitably orient our choice to one or other software.

An initial assessment of the two programmes can already be made, subject to the final conclusions of the comparisons of studies 1 and 2. Both programmes are modular and can be used to handle large scale problems with extensive coupling between elements.

CSTBât/TRNSYS has the advantages that go with the widespread use of TRNSYS and the flexibility of direct programming in FORTRAN of models and, in some cases, of the numerical algorithms. It operates by batch processing and is thus well suited for intensive exploitation of simulators with fixed models. A model library is supplied with it.

figure 7

ALLAN.SIMULATION is very close to the modelling approach proposed here and enables direct transfer between the PROFORMA forms and simulation. It is user-friendly and interactive. The programme has been specified for model creation and validation and for exploration of the operation of diverse variants of a system rather than for large scale exploitation of a simulator. It maskes the numerical and computer worlds.

figure 8

7. CONCLUSION

The approach proposed uses a strict definition of the worlds leading from reality to the simulated worlds. This breakdown of stages, necessary for the primary objective of GAZ DE FRANCE, which is to provide simulation tools for its research engineers, must be reflected in the various transfers between the worlds thus defined :

- the experimenter takes us from "reality" to the "measured" world,
- the modeller from the "measured" to the "modelled" world via his "imaginary" world,
- the numerical analyst from the "modelled" to the "numerical" world,
- the computer specialist from the "numerical" to the "computer" world,
- the model user reaches the "simulated world".

It is clear that each of these jobs requires particular skills and that if no one person is able to ignore any other, all must be specialized in their fields to ensure the most effective overall functioning of the approach.

This specialization requires a strict definition of the points of transfer between the different jobs. Here we have presented the work of the modeller and its culmination : the validated model on a PROFORMA form. We have seen how to make sure that a simulation programme is able to handle the subsequent points of transfer leading to the simulated world.

We have not spoken about the work of the experimenter, whose links with the modeller will be looked at in greater depth in 1991, nor about the work of analysis of simulated and validated results which remains the task of the simulation user.

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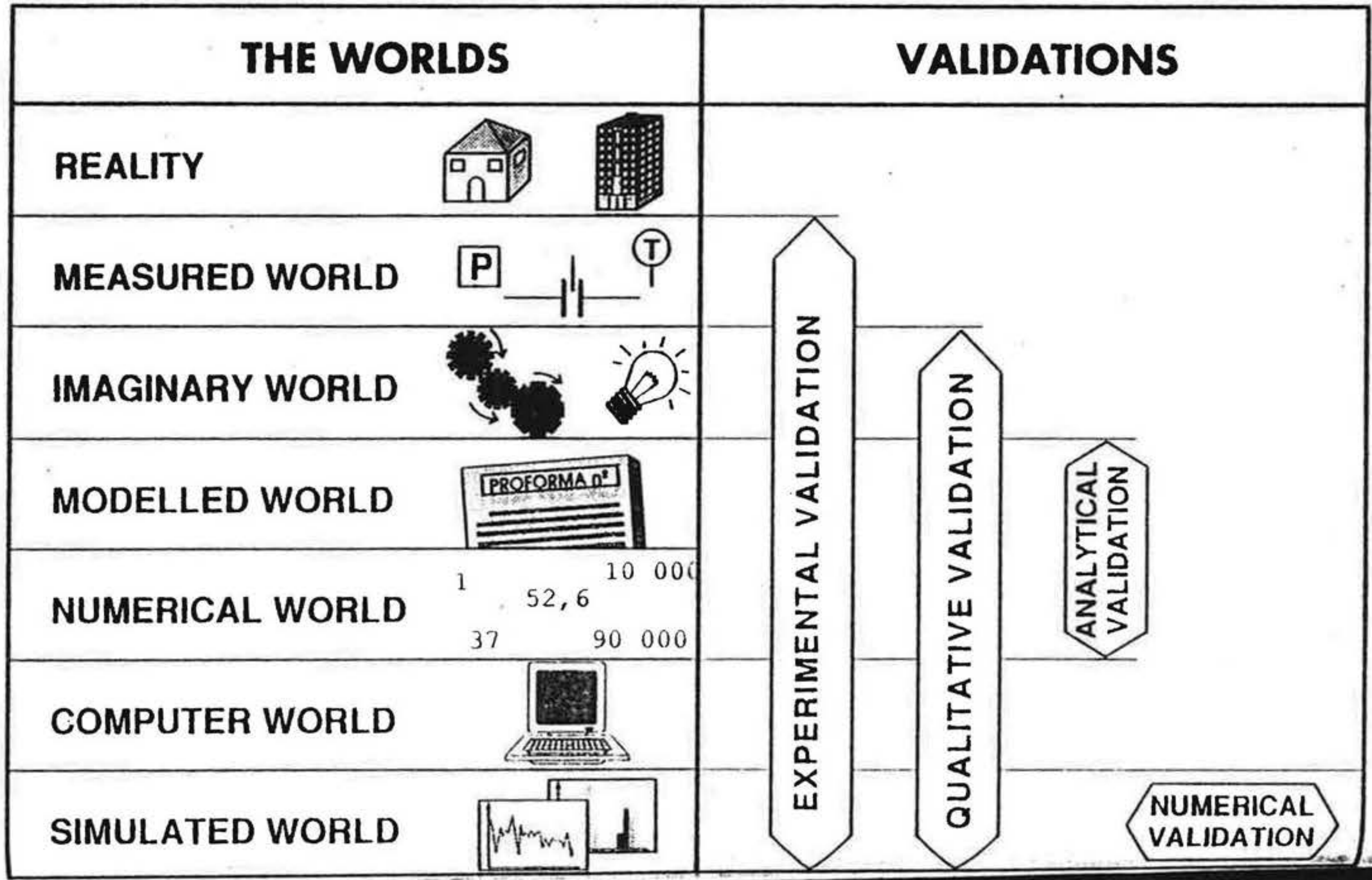
BUILDING THERMAL PERFORMANCE SIMULATION



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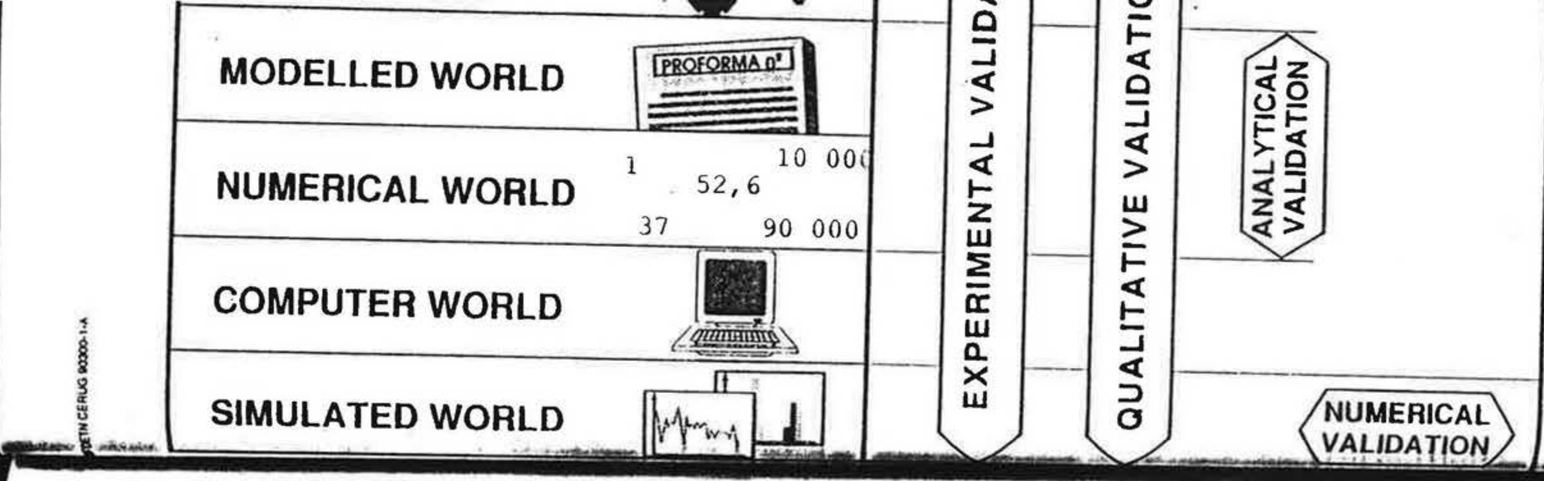
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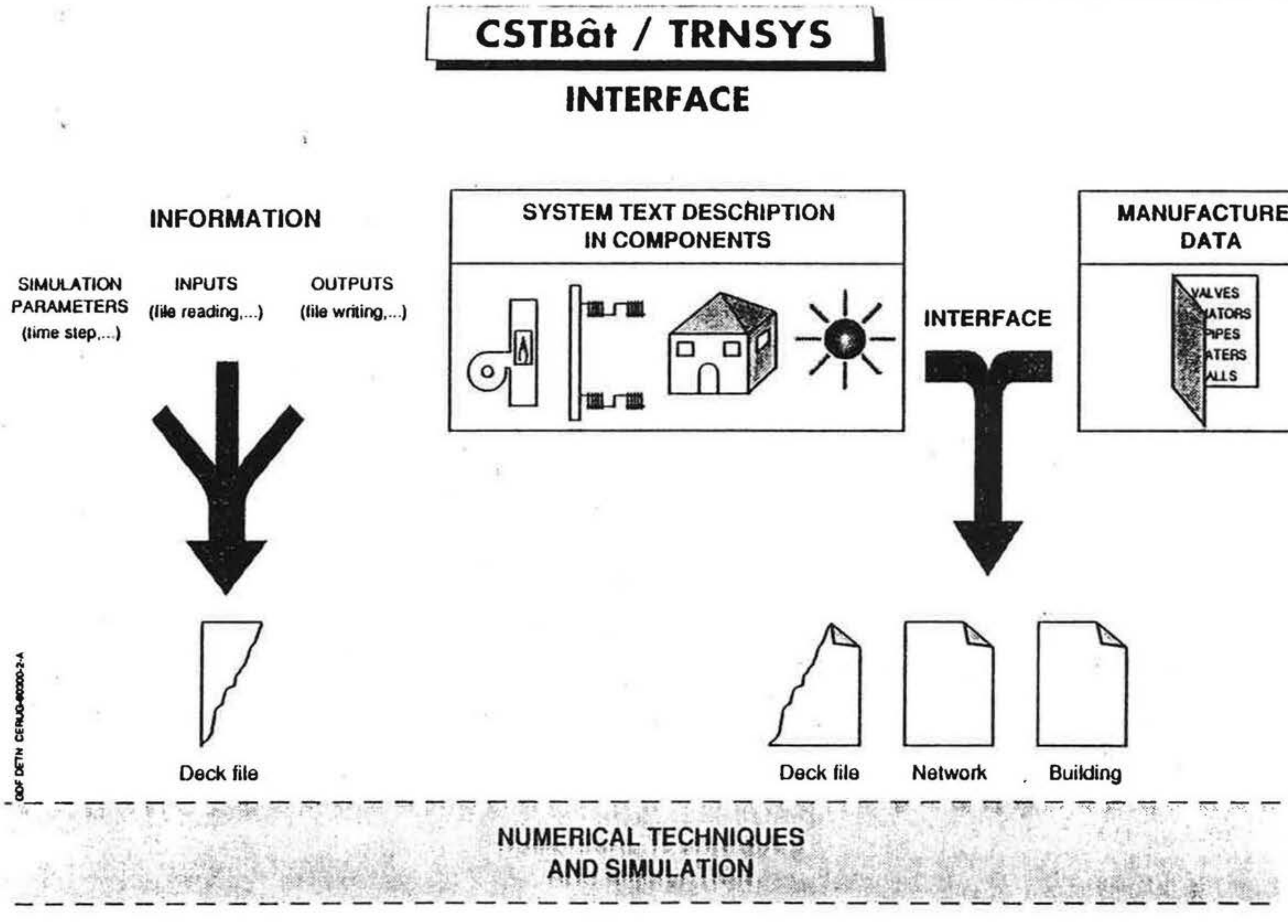
CSTBât / TRNSYS
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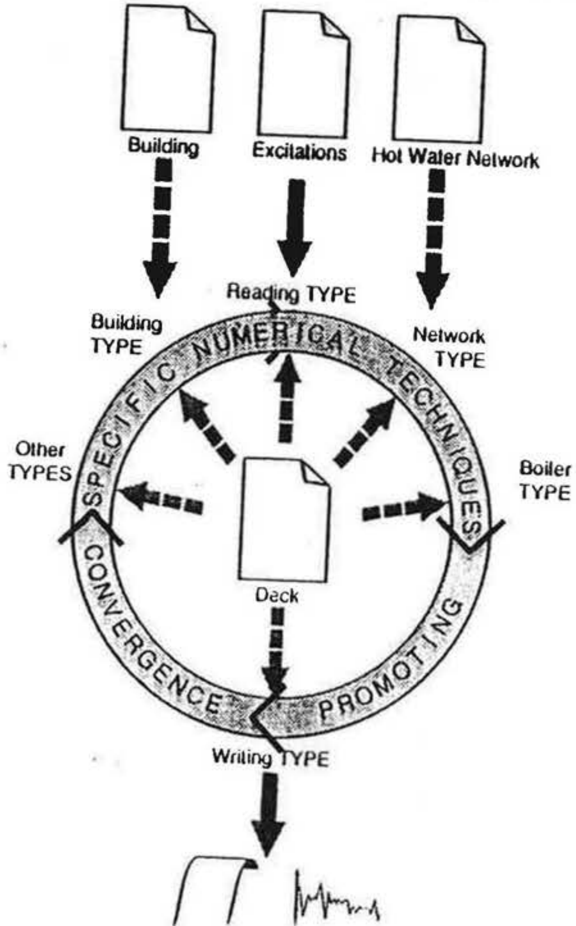
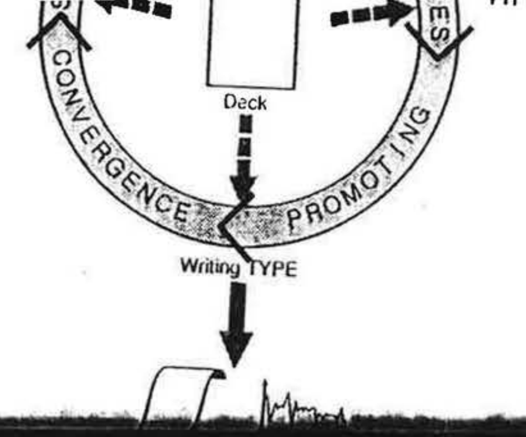
Fig. 2

CSTBât / TRNSYS





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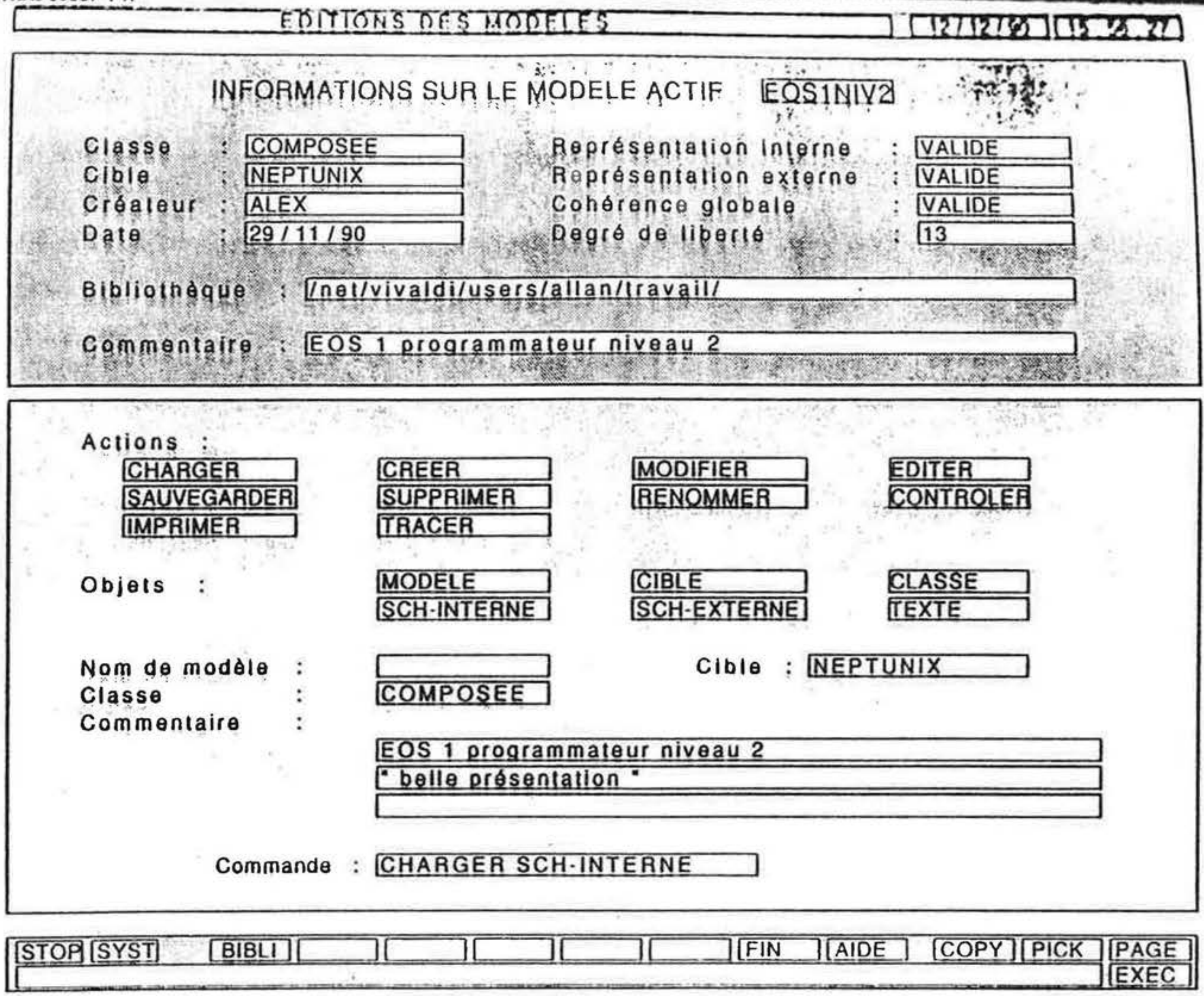

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INFORMATIONS SUR LE MODELE ACTIF EOS1NIV2

Classe : COMPOSEE
Cible : NEPTUNIX
Créateur : ALEX
Date : 29 / 11 / 90
Représentation interne : VALIDE
Représentation externe : VALIDE
Cohérence globale : VALIDE
Degré de liberté : 13

Bibliothèque : /net/vivaldi/users/allan/travail/

Commentaire : EOS 1 programmateur niveau 2

Actions :
CHARGER, CREER, MODIFIER, EDITER
SAUVEGARDER, SUPPRIMER, RENOMMER, CONTROLER
IMPRIMER, TRACER

Objets :
MODELE, CIBLE, CLASSE
SCH-INTERNE, SCH-EXTERNE, TEXTE

Nom de modèle :
Cible : NEPTUNIX
Classe : COMPOSEE
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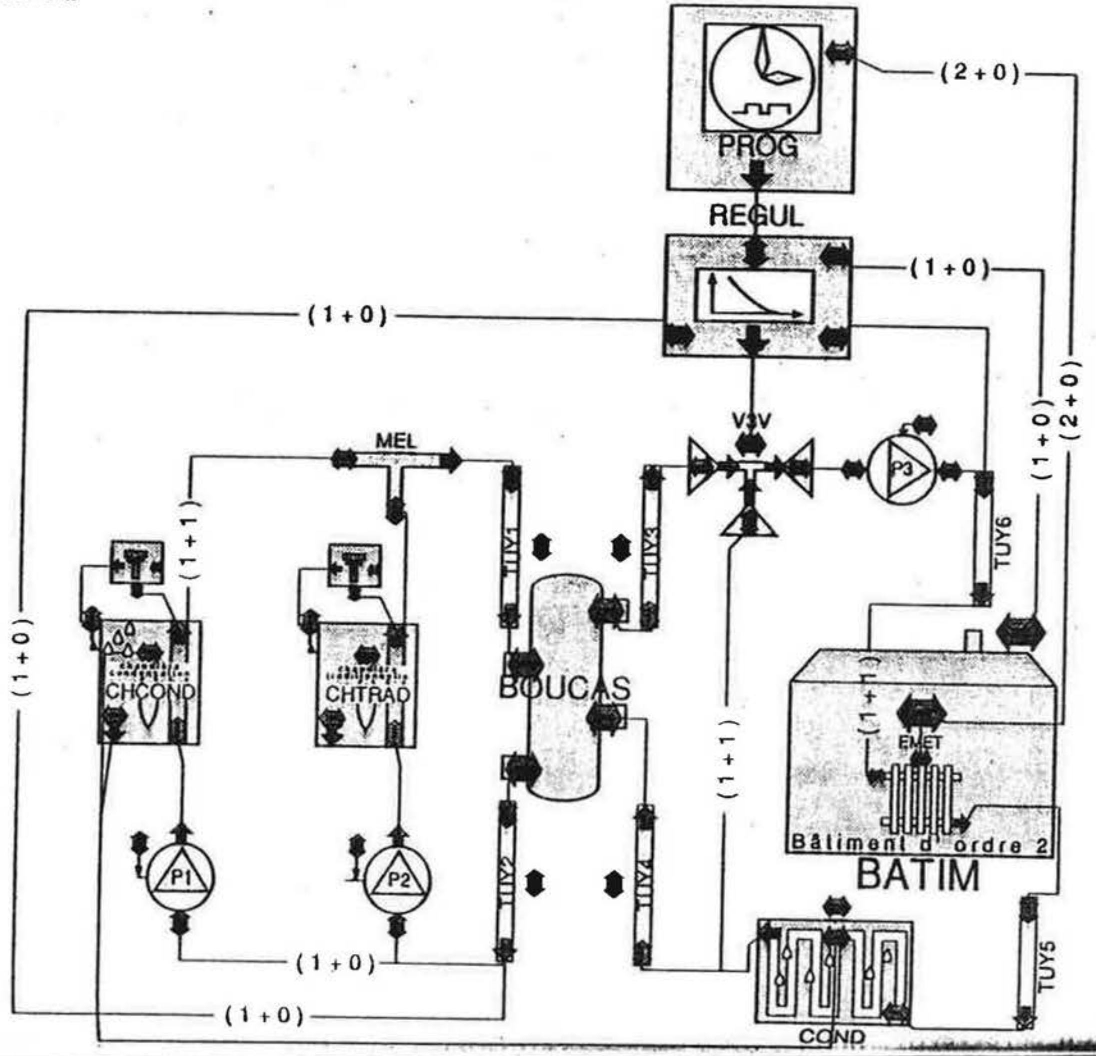
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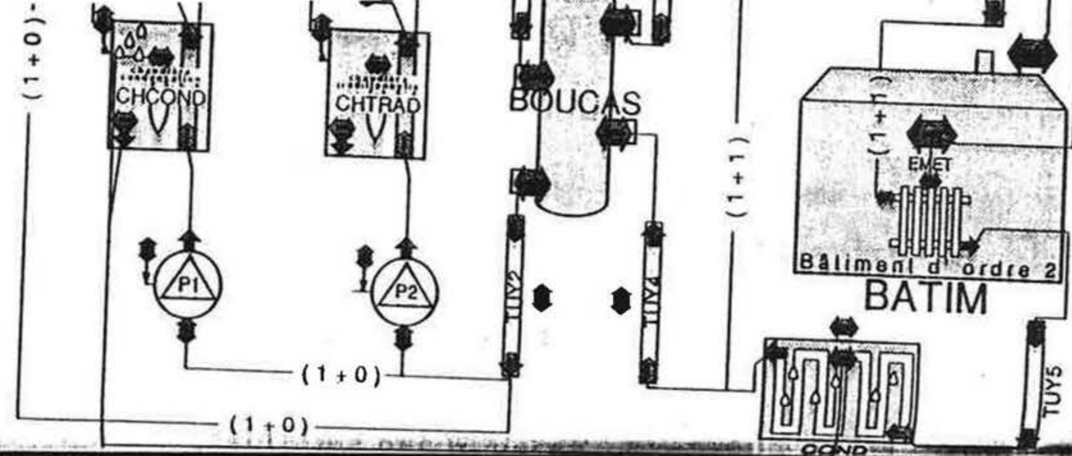
Fig. 5



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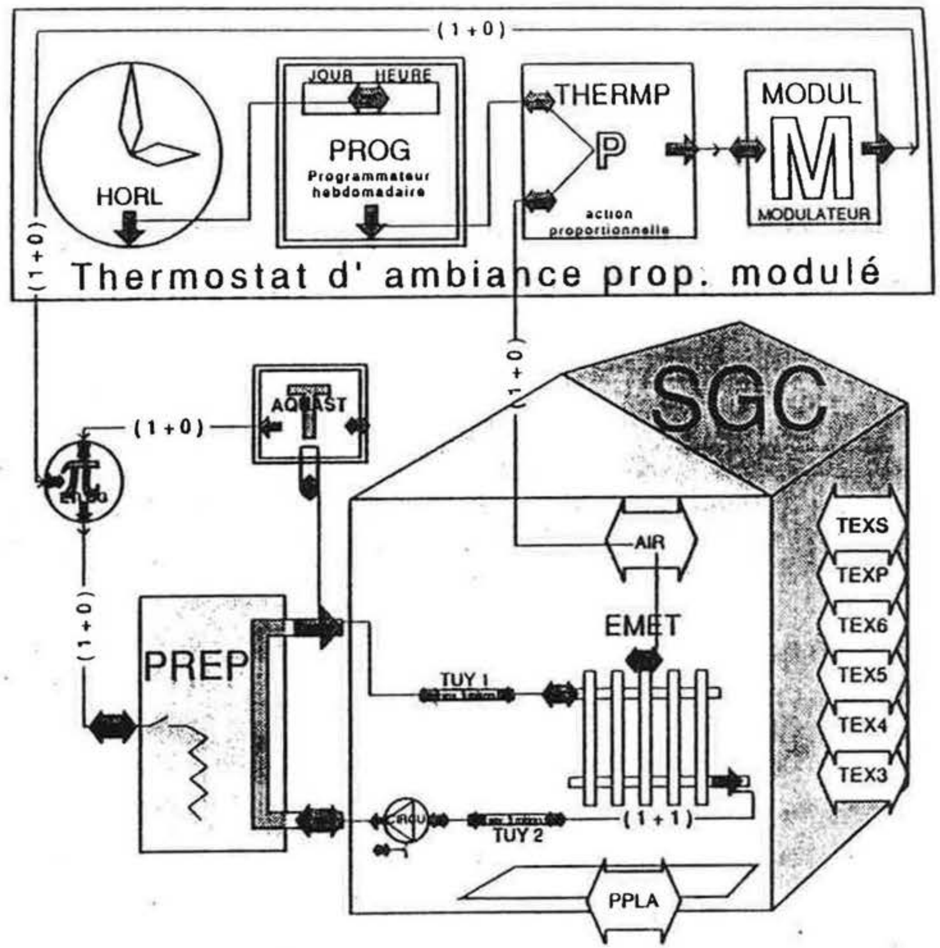
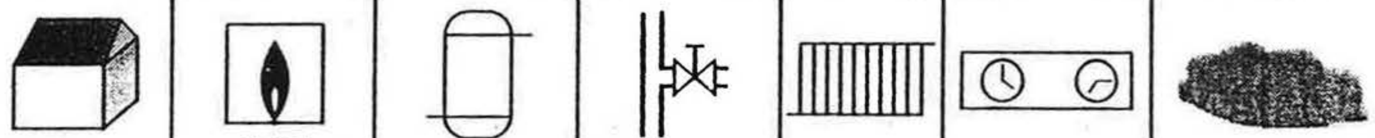


Fig. 6

CSTBât / TRNSYS

A MODEL LIBRARY



BUILDING	HEAT GENERATION	STORAGE	DISTRIBUTION	HEATING	CONTROL	ENVIRONMENT
• sharply modelised	• very simplified boiler	• hotwater storage tank	• pipe	• radiator	• room thermostat	• sunshine
• aggregated	• simplified boiler		• underfloor pipe	• underfloor heating	• three-way valve	
• simplified	• dynamic boiler				• on/off valve	
	• boiler with circulation pump and by-pass				• thermostatic valve	

Fig

• simplified	boiler • dynamic boiler • boiler with circulation pump and by-pass		• underfloor pipe	• underfloor heating	• three-way valve • on/off valve • thermostatic valve	

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Fig.

ALLAN. SIMULATION/NEPTUNIX

Extract of the model library under creation in 1990

BUILDING	HEAT GENERATION	DISTRIBUTION	HEATING	CONTROLS	ENVIRONMENT	MISCELLANEOUS
• Climatic room • Experimental building flat • Identified office buildings	• Conventional individual boiler • Conventional individual boiler with modulated output • Conventional collective boiler • Condensing collective boiler • Heating carpet • Instantaneous water heater	• Mixing bottle • Insulated pipe • Non-insulated pipe • Three way valve • Two way valve • Circulation pump • Motorised valve • Thermostatic valve • Mixing pipe	• Hot water radiators	• Controllers • Thermostats • Schedulers • Clocks	• Average year • Specific days	• Temperature probes • Operating temperature probe

Fig. 8

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DISCUSSION

RONGERE F.X. (France)

How many equations do you solve for this problem ?

ANSWER :

500 for this particular problem as it is shown on figure 5.

NORFORD L.K. (USA)

What kind of equation-solving routine do you use ?

ANSWER :

It depends on the solver you choose to use with ALLAN. We use NEPTUNIX which uses a multistep and variable order method to solve the equations. (see reference for more precise information).

SOWELL E.F. (USA)

1. Is it possible to specify different numerical methods, e.g., integration formulas ?

2. How extensive is the component "Library" ?

3. Are component models "input/output oriented" ?

4. Is reduction performed on equations ?

ANSWER :

1. With ALLAN simulation, it is possible to choose between two different solvers : ASTEC3 and NEPTUNIX.II. If you wanted to choose another one, you would have to develop a program that translates the ALLAN inner language into the entry language of the solver you want to use. This part of the ALLAN software has been made modular to make this kind of action possible.

2. I can only estimate the number of components existing within Gaz de France in the field of building simulation. I would estimate the number of equational models to 80 and curve fit ones to 140.

3. Using the NEPTUNIX solver, which is always our case, the answer is no. Equations may be implicit and the "orientation" of the model depends on the sollicitations you use.

4. No, none of the solvers used with the commercialized ALLAN performs equation reductions.