AN APPROACH TO THERMAL MODELLING AND SIMULATION OF BUILDINGS AT GAZ DE FRANCE

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ABSTRACT:

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

Emphasis is placed on modelling and its validation. In the proposed approach, a model library in the form of PROFORMA forms is set up. Its aim is to provide researchers with a set of models characterized, in particular, by their state of validation.

The engineer selects the models and the simulation tool he needs in order to obtain the numerical results corresponding to the objectives of his study. The simulation can be made using a range of software, including CSTBât/TRNSYS and ALLAN SIMULATION/ NEPTUNIX.

The different model validation techniques, experimental validation in particular, enable us to make headway in our understanding and in the design of new products.

This approach aims to make optimum use of the models and softwares. The initial work carried out in the context is presented.

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.

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.

Two investigation methods have been implemented in parallel : full-scale testing and numerical simulation. the GAZ DE FRANCE test facilities have been described in a number of presentations which are well worth reading [PERRAY 87], [CASSAGNE 89]. Here we are more especially interested in numerical simulation.

THE ROLE OF SIMULATION

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 skill in the use of the simulation tools thus makes it possible to overcome technical and physical problems and provide a concrete answer to the question in hand.

A GENERAL APPROACH

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.

These fields are broken down in worlds, shown on the figure number 1.

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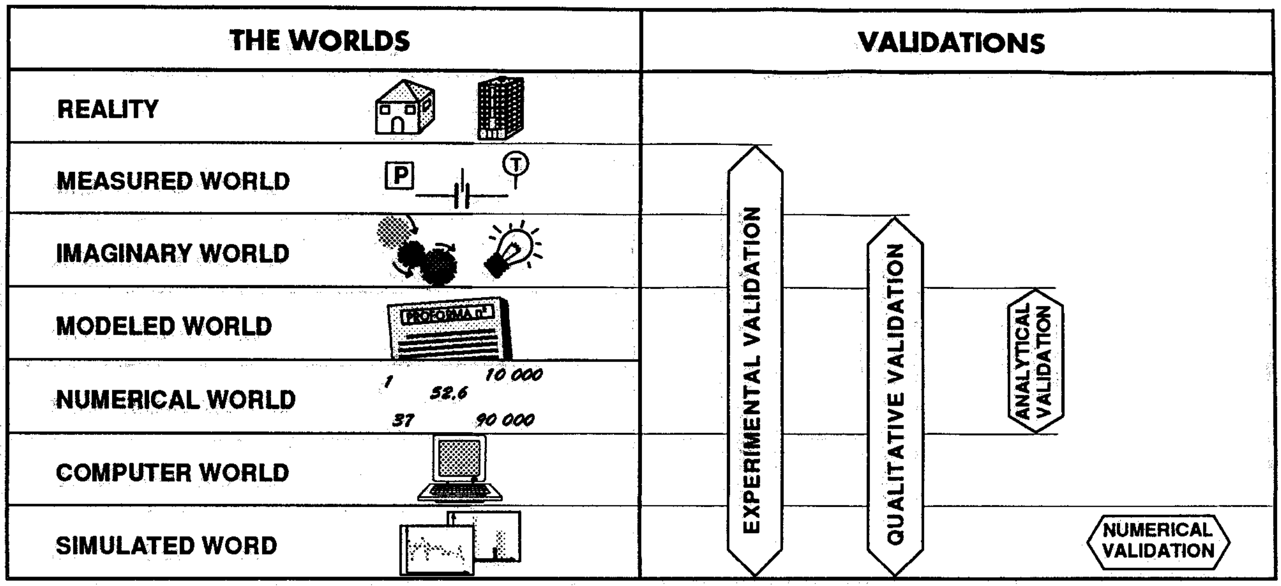

Figure 1 : Building thermal performance simulation

In this breakdown of tasks, we are concerned by modelling on the one hand and simulation on the other. We are therfore interested in the "imaginary", "modeled" and "simulated" worlds.

We wanted to introduce the "imaginary" into this breakdown, which has now a standard reference at GAZ DE FRANCE [POTTIER 88], as it is not sufficient simply to formulate mathematical equations of phenomena. The skill and judgement of the modeller must also be brought into play.

This specialization required a strict definition of the transfer points between the various tasks corresponding to the different worlds. It ensures that the particular skills of each are used to optimum effect.

Here we will present the work of the modeller ans its culmination : the validated model on a PROFORMA form.

We will then see how, on the basis of model descriptions in the physicists natural language, the ALLAN.® SIMULATION/NEPTUNIX [CISI 90a] software is able to handle the points of transfer from the model to simulation and to exploitation of results. ALLAN.® SIMULATION/NEPTUNIX is a general software for model-description and simulation of any dynamic systems.

We will also show how, thanks to the work of the CSTB (French Scientific and Technical Center for the Building industry) [LARET 88], this CSTBât/TRNSYS software simplifies the operation of a simulator with a large building system model library.

Finally, the model quality is guaranteed by a strict validation procedure.

Let us assume, therefore, that the problem has been perfectly defined through dialogue between the project head and the modeller. The modeller will have to choose his models and maybe create and validate new ones. His starting points are the expected simulation results (variables to observe for carefully chosen excitations) and the system to be considered as a whole.

MODELLING BY COMPONENT ASSEMBLY

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

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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.

This approach gives rise to a number of difficulties. There is no single solution and the processes includes numerous backward steps.

The complete system is obtained by assembly of the different component models. Of course, the question of how models should be connected to each other then arises. We will see that, depending on the type of link between the components, we move to a greater or losser extent from the "modelled" world to the "computed" world. The two programs presented later are not equivalent in this respect.

We must therefore 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 [DUBOIS 86,89,90]. 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 produce 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 an other 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.

In order to be validated and in order to achieve our study objectives, these models must be included in simulation software.

Models must be used in simulation to be validated. GAZ DE FRANCE possesses several simulation programs, of which only the two mentionned above 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.

ALLAN. ® SIMULATION/NEPTUNIX (Description and Simulation of any dynamic system).

ALLAN.® SIMULATION [CHOUARD 84], [FAVRET 88] 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 and manage models for the NEPTUNIX 2 simulation program [CISI 90b]. It may also be used with ASTEC 3. We will only speak about its application in the field of building simulation.

Simple models

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/ouput terminals to which other models can be linked). The model description is based on the phenomena to be taken into account and may remain implicit.

With ALLAN.®, a thermal capacity may be expressed as follows :

0 = -C*T' + FLUX ;

where T is the temperature characterized by its unit "%C", FLUX, the thermal flux characterized by its unit "W" and C the model parameter. The apostrophe indicates the total derivation with respect to the independent variable, here time. We note that the expression is non-oriented as the orientation results from the assembly of the model with others and from the choice of command variables, also called excitations.

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Compound models

By associating simple models graphically, compound models are created which, in turn, can be used to create other models. The models are connected at this level by the physical relations between objects, i.e. the connection of two mdels directly involves the laws of conservation of extensive quantities and the identities of intensive variables.

In all cases, the model is characterized by its degree of freedom. This is the number of command variables whose values must be specified in order to fully define the model behaviour. Provided that formulation is appropriate, it is only at the moment when commands are chosen, that the model orientation is defined.

The problem

When the system to be studied exists in the form of a simple or compound model, excitations must be associated with it by means of an excitation model (algebro-differential equations, value tables and/or data files). What is called the problem is then created.

The preprocessor provides the simulation program with the complete problem to be solved in the right form.

Two simulation programs are currently available : NEPTUNIX 2 and ASTEC 3. We use the NEPTUNIX software. It carries out the simulation of linear and non-linear processes. It uses a multistep and variable order stiff method. It is able to accurately and efficiently simulate systems which have discontinuous elements, and yields satisfactory results when synchronization is necessary. It generates the simulator as a FORTRAN program that can be used as such or as a routine by another software.

If it proved necessary, it would be possible to write a translator towards a new simulation program, as the computer programming of the sofware is well adapted for this.

ALLAN.® SIMULATION then handles the graphic processing of simulation results. This capacity is also used for results from other sofware, including 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.

A large model library has been created (figure 2) :

The models were created for two studies conducted by GAZ DE FRANCE : **"Study of the operating strategy of a boiler plant for a commercial building"** [D'ACREMONT 90] and **"The comparison of individual hot water central heating control systems"** with a fine building model (a two-room apartement of the GAZ DE FRANCE experimental building and the research center's controlled environment test room).

ALLAN.® SIMULATION also manages the model libraries. A clear distinction is made between the user's working library and the secondary read-only libraries.

BUILDING	HEAT GENERATION	DISTRIBUTION	HEATING	CONTROLS	ENVIRONMENT	MISCELLA-NEOUS
● 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

Figure 2 : ALLAN.® SIMULATION / NEPTUNIX - Extract of the building model library

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CSTBât/TRNSYS

CSTBât is an environment used to simulate the thermal behaviour of a building with its heating equipement. It has being applied to appartements of the experimental building of GAZ DE FRANCE. CSTBât is based on TRNSYS.

TRNSYS was developed at the Solar Energy Laboratory of the University of Wisconsin in Madison and marketed in 1975 [KLEIN 88].

TRNSYS is a modular system simulation software to study transient systems. It is written in FORTRAN and is flexible to use as each modelled entity 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 algorithms, including one for the calculation of systems of equations of state by matrix exponentials, suitable for linear problems as used to describe the building. 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 [LARET 88] as part of a research contract and are currently being validated by GAZ DE FRANCE.

The different models can be used for a range of analysis levels so as to provide a correct response to a wide range of studies. With a large range of available component models, it thus becomes possible to build an overall model of any system to be examined. For example, parametric studies, analyses of extreme operating conditions, especially when predicted breakdowns occur, comparisons of different structures can be made rapidly and conclusions can be drawn from the results. For interesting cases only, verification in the field followed by subsequent matching of the model are necessary.

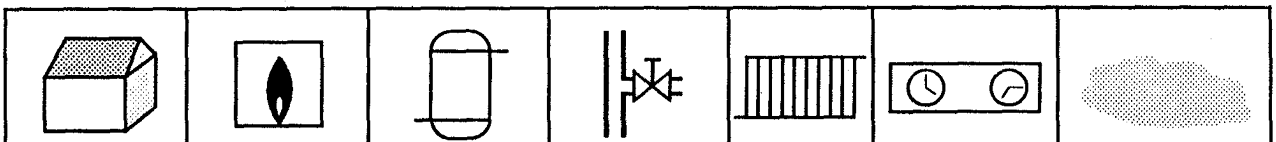
As prevously mentioned, a basic model library had to be set up at the outset. In order to exploit the full range of combinations, models had to be easily connectable.

Moreover, the different types of study require different description levels and hence different models. There must therfore be a correspondence between the model parameters at all description levels [LARET 89,91a].

To attain these objectives, generic models adaptable to different description levels were defined for all elements.

These models are presented in a separate paper at this conference [LARET 91b].

The physical problem of the building subjected to its environment and to the operation of its heating equipment (controlled by variable indications which may be measured inside the building) is thus broken down into a library of models (figure 3).



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	

Figure 3 : CSTBât / TRNSYS - A model library

MODEL VALIDATION APPROACH

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.

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.

This type of validation was used to compare the thermal behaviour of the same studio on ALLAN.® and CSTBât. No difference was observed between the numerical results.

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.

This type of validation is used regularly in the model development phase.

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 and that the right phenomena have been taken into account. 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.

For this, different types of excitation can be considered :

- standard excitations,
- nominal or legally required conditions,
- extreme or limit conditions.

For standard excitations : each of the model inputs or inputs/outputs, and only one per simulation (the others remain constant), is excited by a standard excitation : up step or down step. Conditions for the value of the model variables are associated with them (for example : input water temperature of radiator is not less than the ambient temperature).

The behaviour of outputs is noted and compared qualitatively with the expected behaviours, for the model and the excitation applied. Results are presented by model. Simulations are grouped in a table.

As regards nominal conditions, the model inputs are chosen according to standardized test and the outputs are observed with respect to these tests.

The model can be used in "extreme" conditions (for example : water temperature equal to ambient temperature and zero flow at a radiator inlet). This type of validation defines the limits of validity of the model.

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.

This is particularly true for experimental, for which the approach involves systematic validation of the isolated object followed bu coupled objects in open then in closed loops.

Each model is used for one (or more) tested physical object(s). The parameters are deduced from technical documentation about the tested and simulated object. The input is experimental data. The simulated outputs are compared to experimental data (outputs). This comparison provides information about the relevence of the phenomena taken into account and also about the models for calculation of the model parameters on the basis of technical characteristics of the objects.

Validation may concern transient or steady states. Errors in the experimental measurements used for model input and output are taken into account. A qualitative study is made by plotting superimposed simulated output-experimental output curves alongside a

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quantitave study involving calculation of criteria between the two curves.

In qualitative terms, the model is valid if the curves have the same shape (the outputs have the same dynamic behaviour). Quantitatively, the difference between simulated and experimental outputs should be acceptable, and below the measurement uncertainty if possible. However, the preferance for using general rules for choice of parameters sometimes makes it necessary to accept slightly larger difference.

Validation results are recorded on the PROFORMA forms.

MODEL VALIDATION

Models described under ALLAN.® or implemented under CSTBât are being systematically validated by GAZ DE FRANCE. As stated above, qualitative validation is considered to be vital.

GAZ DE FRANCE is equipped with unique testing facilities and has devoted a large part of its effort to experimental validation. Initially each model was validated independently.

For example, the simplified building model on CSTBât was studied. Similarly, each heating network component model was subjected to the various validation phases described above [PALERO 89]. Numerous tests conducted on heating components in the experimental building were used for experimental validation, both with CSTBât and ALLAN.®.

To date, no proper experimental validations have been made for a coupled building equipment problem.

It should be underlined that validation becomes rapidly more difficult as the complexity of the system studied increases.

CONCLUSION

We placed ourselves from the outset in the role of the modeller and user of simulation tools. We have seen which approach should be adopted in order to model systems and how the notion of PROFORMA can be help in this approach and make it possible to capitalized on our knowledge.

The models are used with the two programs.

CSTBât/TRNSYS has the advantages that go with the widespread use of TRNSYS. It operates by batch processing and is thus well suited for intensive exploitation of simulators with fixed models. The model library was supplied by the CSTB and a wide range of TRNSYS models are available in different laboratories troughout the world. The model coupling phase may still be tested to ensure complete reliability of results.

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.A library of thermal building models has been implemented under ALLAN.® SIMULATION and is currently being validated. We may assume that the validation work ignores the transfer from modelled to simulated world as it is handled by the program.

The first comparison between the programs 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, within the constraints imposed by company life.

Modelling is of no value if the phenomena and the parameter calculation are not validated on the basis of the technical characteristics of the objects studied. We have presented the approach adopted by GAZ DE FRANCE to ensure the quality of models.

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