Towards a new generation of building energy analysis tools

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Summary :

While knowledge in the building energy modeling has made considerable progress since 1970 - because of a better computer aided understanding of the building thermal physics - the access to this body of knowledge remains limited for both practitioners and researchers of the building sector. The building energy simulation tools, developed since 1975, have surely contributed in this way, offering powerful analysis facilities. But, although these energy analysis tools were especially designed for commercial users, we report they stay restricted to a small number of building design firms. As to the research community, the current tools have software frameworks too inflexible to introduce models with different levels of complexity. We attempt to review the existing simulation tools to explain the reasons of their limited diffusion. We point out that different parties of the building sector have different needs in terms of building energy analysis tools. Several european and american research laboratories involved in the field agree on these weaknesses and have decided to gather their efforts to develop a new generation of building energy analysis tools. We describe the French participation in the international organization which has been set up to this end. On the basis of a more structured simulation approach, the French proposal is finally exposed. It stresses the need for a common computerized framework to give users access to a calculation and data base to carry out a large range of studies at different levels of complexity.

Vers une nouvelle génération d'outils d'analyse énergétique du Bâtiment

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MOTS CLES :

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Sommaire :

Alors que la connaissance en matière de modélisation thermique du bâtiment a considérablement progressé durant les quinze dernières années - à cause d'une meilleure compréhension du bâtiment, grâce aux moyens informatisés - les accès à cette base de connaissances restent encore déficients pour le secteur du Bâtiment. Les outils informatiques de simulation développés depuis 1975 ont certes contribué dans ce sens en offrant des moyens puissants d'analyse. Mais, bien que ces outils d'analyse énergétique furent particulièrement conçus pour les professionnels, nous constatons qu'ils restent limités à quelques bureaux d'études. Quant aux chercheurs, les codes existants s'appuient sur des cadres souvent trop rigides pour introduire des modèles détaillés en des composants spécifiques. Une étude critique des outils existants est menée afin d'identifier leurs faiblesses et de saisir les causes de leur diffusion limitée. Elle conduit également à dégager, pour chaque groupe, des besoins spécifiques en matière d'outils numériques d'analyse. Les principaux laboratoires européens et américains impliqués dans le domaine s'accordent sur ces constatations et ont décidé de rassembler leur efforts pour développer en commun une nouvelle génération d'outils de simulation. Nous présentons la participation française à l'organisation internationale mise en place à cette fin. Sur la base d'une approche plus structurée en simulation, la proposition française est discutée dans ce papier. Elle insiste sur le besoin d'un système informatique fédérateur offrant des moyens de calcul partagés dans un cadre commun, cette vaste structure d'accueil étant mise à la disposition des intervenants du secteur pour mener une large gamme d'études à différents niveaux de complexité.

1. Introduction

Since 1960, many studies have been carried out around the world to develop calculation methods - or algorithms - in an attempt to improve our ability to model the different phenomena encountered in building energy research. These studies have, in particular, allowed us to introduce the classical formalism of disciplines associated with applied physics into a domain which had previously been dominated by experimental methods. The introduction of the computer at the beginning of the 1970's generated interest not only in applying computer techniques to these methods, but also in integrating them in a computerized framework.

The result has been the development of a wide range of computerized simulation tools, principally in North America (1), but also in Europe (2). Mention should be made of DOE-2, BLAST, NBSLD, TRNSYS, ... in North America : and ASTEC (3), CALECO/DOE-2 (4), CSTBât (5), ESP (6), LPB (7), ... in Europe. In terms of the computer-aided analysis which these "first generation" simulation programs have given, we can say that they have brought designers the first estimations of building energy efficiency, and have so contributed to a more accurate sizing of envelope components and HVAC systems.

While demand for simulation tools has never been so important as a direct consequence of the increasing adoption of computerized methods in the building sector (in particular in Computer Aided Design), we shown off the gap between the capabilities of the existing tools and what it is expected today in terms of software products and analysis approaches. Quite often, the tools proposed have been too complicated to be used without considerable programming experience, and too limited in their field of application.

At the present time, although thermal modeling of buildings has made considerable progress since 1960 (because of a better understanding of building thermal physics and thanks to computerized tools), access to this body of knowledge is still limited for the different parties which compose the sector.

At the end of 25 years of work, it is useful to pause and look closely at these softwares which are currently available to researchers and designers in the energy analysis field, and also to look at the kind of studies which could be carried out. This survey is led around two questions : for who and to do what ?

2. Simulation tools : for which users ?

Even though these computer programs were developed primarily for the professionals in the building sector, their use remains limited to relatively few engineering firms and some research laboratories. In addition, the few offices which have recourse to this programs, run them in the final stages of the design process, when the decisions have no more significant effects on the costs. A critical review was carried out in 1984 in order to identify the weaknesses of current programs and to grasp the reasons for their limited diffusion. The study also led us to distinguish, for each group of potential users, specific needs for analysis tools.

The users community can be divided into six groups : designers, researchers, builders, manufacturers, education and regulatory authorities. This inventory helps us to identify for each group, specific performance criteria for a simulation tool. Some of them are illustrated below.

In the design field, "Speed" and "Ease of Use" are key features. That is the reason why a lot of existing simulation programs have difficulties in being run for commercial applications. They request a long time of practice to be an initiated user. In most cases, they are also bad adapted to the problems posed because of a lack of "Versatility", very inconvenient to evaluate, in preliminary design for exemple, some alternatives (what's if). One consequence is that designers overuse microcomputer programs whose "User-friendliness" lives sometimes down the limited potential of analysis.

In the research field, "Detailed Localized Analysis" ("Zoom Effect") to focus on one part of the system could be frequently a key feature. It supposes that for a given component, the tool can offer a model with different levels of complexity which could be at every moment refined by the researcher. Now, the programs created in the past have locked up the basic formulations of the models in the source code (FORTRAN mostly) so that they propose only one level of modeling without refinement ability. Even if the source code is at the user's disposal, any modification of a model requires very large investments of time and energy for programming and numerical analysis - often to the detriment of physical analysis of the phenomena concerned. The era of models locked up in a machine code and accessible only to programmers is definitely over : it must now be possible for a advanced user to set up his own model of a problem without having to learn a programming language first.

3. Simulation tools : for which investigation ?

Ignoring the obstacles directly associated with the difficulties of using the computer programs, we can identify two types of analysis approach which remain partly of wholly unsatisfied with the simulation tools presently available.

A building is a complex system which integrates, under given climatic conditions, components as varied as load-bearing walls, interior walls, windows, space air volume and equipments ; some of these components being subject to more or less sophisticated control systems. The analytical approach which has most often been adopted to come to an understanding of the dynamics of this system is generally that of detailed analysis. The action of modeling is reduced to stack piecemeal and more or less elaborate models of each component. This is clearly shown in the modular structure of some existing programs (5, 8, 9)

This type of approach finds its bounds specially when the interest is focussed on a detailed examination of the relationships between the building envelope, the equipments, and the control system. In such a study, the time base for analysis should to be reduced according to the smallest time constant of the system. But this constraint imposes more accurate models to take account some physical phenomena (convection, air or mass transfer) which become dominant at low time step. In practice, the existing tools do not accept models with different degrees of complexity.

In addition, the one and only process of numerical solving (buried in the program code) does not in general permit the co-existence of components having time constants which are so markedly different as space air volume, thermostats, equipements or foundations (stiff problem). So, most of the tools are unable to satisfy such an investigation and give illusion to the user that reducing the simulation time step is enough.

But a detailed simulation of thermal dynamics is not always the best approach for building energy analysis.

In particular, it is not appropriate when the objective is to take out a overall behavior of the system. A well-known application is the assessing of overall thermal performance, for example through the building heat losses over an heating season. To perform such an estimation with the existing programs (as a consequence of their mono-functionality), an hourly time step simulation has to be run even if U (K in France) coefficient models would be the best adapted method.

An other important restriction concerns all the plans involving a control system. They are frequently found for commercial buildings where the energy management finds the best field for application. But unfortunately only a few tools (10,11) are really able to assess or to compare a control system vs an other. Essentially because the presence of controlled variables (for example, a space air temperature) imposes a complete re-formulation of the problem in terms of the control theory.

Some programs attempt to show that it is possible to get around this obstacle by using powerful numerical integrators with low time steps. But they ignore the presence of the controlled variables. In fact, these variables introduce a major constraint which must be taken into account if the investigation is really to understand the dynamics of the coupling between envelope, equipment and control system.

It is rather a choice of an adapted approach of analysis (the control theory) than a matter of solving technique power. In the control theory approach, the building is analyzed as a "system" viewed from the outside (black box) and whose behavior is caracterized by low-order models (differential equations or transfert functions). These models has to be simplified enough to allow various "system analysis" techniques (parameter identification, model reduction (12)) to be applied. That is the necessary passage point to define the control laws (strategies) of a building under a set of given constraints. Such an approach was selected by the French research group IRCOSE to implement optimal control strategies in a twin-energy heating dwelling system (13).

At this time, we can just regret the almost absence of these techniques from the existing tools which does not promote the emergence of economical control systems.

In other respects, opening up the present codes to the control theory techniques - already widespread in other disciplines - would limit the arbitrary elements which exist at present in the development of simplified models. This would also permit better calibration of models using experimental data and would partly open the way to solve the problems posed by the validation

of models.

Reporting this ever-increasing gap between the developers of simulation programs and the people using them (14, 15), several laboratories in Europe and in the United States have decided to co-ordinate their work in order to develop a next generation of thermal simulation tools which could become operational by 1990. In the framework of the International Building Performance Simulation Association (IBPSA), an international organization was set up in 1985 on the initiative of Lawrence Berkeley Laboratory (LBL) with this as its objective. This association is organized around five main centers :

- In France, on the initiative of the Agence Française pour la Maîtrise de l'Energie (AFME), three teams have agreed to participate in the task : RAMSES/CNRS Team (Orsay), UTI/FNB (Saint-Rémy-les-Chevreuse) and SEBE/CSTB (Sophia Antipolis, Valbonne). The French participation, under the leadership of the AFME, is organized in the framework of the "Groupement d'Etudes et de Recherches" (GER) ALMETH (ALMETH Research Group) (*).
- In Europe, several laboratories which are already active in the development of building energy analysis software now work in conjunction with IBPSA. Notably, the ABACUS Group at the University of Strathclyde, and the Laboratoire de Physique du Bâtiment of the University of Liège.
- In the U.S.A., the Department of Energy has assigned the Lawrence Berkeley Laboratory to lead the project. Other laboratories have agreed to contribute to the task, notably the National Bureau of Standards who have worked closely with the Centre Scientifique et Technique du Bâtiment since 1977, the CERL Laboratory of the U.S. Army, the University of Wisconsin and the California State University.
- We should also mention that Canada and China are associated with the project through respectively Public Works Canada and the Chinese Academy of Sciences.

5. Proposal by the French component of IBPSA

At this time, a work plan (16) is proposed by LBL/ABACUS Groups to develop a KERNEL SYSTEM of highly-portable software modules ("SOFTWARE PRIMITIVES"). More than propose a single program, they want to provide an environment (KERNEL) in which anybody will be able to construct customized tools. They refer to works on computer graphics (GRAPHIC KERNEL SYSTEM) and on operating systems (UNIX).

The GER ALMETH agrees that advances in computer sciences bring powerful processing techniques but keeps in mind that the essential function which the tools have to assist is the computer-aided analysis on a physical system (building). In this field, the choice of a method can appreciably affect the results of an analysis and, at every time, it must be possible to review the model formulations (equation or algorithm) at the user's request. This capa-

(*) Atelier de Logiciels pour la Maîtrise de l'Energie dans le Tertiaire/Habitat.

bility (which gives to the next tools a better "Transparency") is now possible with advanced knowledge data base systems which separate modeling aspects from the computerized aspects.

Accepting this challenge, the GER ALMETH approach is to develop a common computerized framework to give users access to a model and calculation data base. Practically speaking, the work carried out has two components (15). The first is in the domain of physical analysis, and is aimed at structuring the knowledge in building thermal modeling. This task consists to build up a "Model Library" which will gather all the models used in the field. The second approach is concerned only with the computerized aspects of the project and aims at making this body of knowledge accessible to all who are active in the building sector, thanks to a common computerized framework.

ACTION PLAN n°1 : Modeling of physical phenomena and numerical analysis

In contrast with what is happening in North America (1, 17) and at a smaller scale in certain countries under the leadership of the International Energy Agency (18), France has previously made little investment in co-ordinated research projects to analyze, compare or test models of physical phenomena in building energy analysis. This is despite the fact that many studies have been carried out but without the possible/potential uses of the results in general simulation codes being made clear. An important effort is now being made to change this situation, and this is one of the key aspects of the French context.

That is one of the missions of the GER ALMETH through the ACTION PLAN n°1. The first task is the census of the large number of models which have been developed in the past. These models are frequently buried inside thousands FORTRAN lines of complicated computer programs and only the program writers really know how to have access to them. It is therefore essential to extract the basic formulations of the models and to gather them in a "MODEL LIBRARY" (called the "MODELOTHEQUE" in France).

In parallel with the developement of this Model Library which consists essentially in developing a data base management system (cf. ACTION PLAN n°2), it is important to standardize the format around the "MODEL" object. That is what we call a "MODEL PROFORMA".

Keystone of the Model Library, the MODEL PROFORMA is a descriptive sheet which meets all the technical informations (thermal, numerical) for a given model. All the knowledge around is then structured through this standardized form useful for :

- building up the textual data base placed at the disposal of all the people involved in the modeling aspects ; the whole constituting a reference textbook ;
- outlining the specification stage of the "MODEL OBJECT" before elaboration of the software component corresponding ;
- helping the user to choice the best adapted model to the problem posed thanks to validity clauses and rules of use or practice.

Inspired with the "DATAPROCESSOR PROFORMA" (19) proposed in 1984 by the ABACUS and LPB Groups to the I.E.A. working Groups, a first draft of the MODEL PROFORMA (20) was released by the GER ALMETH after a consensus between all the research teams involved in the field (INSA, CSTB, ENSMP, FNB and AFME).

The concept is improving through bench tests on well-known applications in order to complete its expressive ability. At this time, the current version contains five chapters.

A first chapter gives synthetical information through a generic name, an abstract, and various spaces to be filled,pointing out the type of methods used and the kind of model validation. A second chapter concerns the formal description of the model illustrated by functional and I/O schematics. But it is also essentially the place of the mathematical formulations which can exist under the forms of equations, algorithms or logical rules. The third describes the application field listing the validity clauses, the rules of use and the specifications of assembling with other models. All the informations on validation attempts are gathered in the fourth chapter. Finally, the fifth gives the author details and the bibliographical sources.

The (model,proforma) doublet constitutes an element of the model library and whose the access is assured by the data base management system. The proforma appears really as a template of building thermal modeling knowledge expression and thereby prepares the advent of expert systems in the simulation field. They will allow notably an automatical selection of the model the best adapted to the problem posed.

ACTION PLAN n°2 : Giving access to computer programs

The computer-based aspects of the common framework constitute the second part of the project.

The inventory of the different types of users (cf. chapter II) has helped us to identify specific performance criteria for simulation tools, and has demonstrated that one single program cannot satisfy such a diverse audience. From which the idea to build up a common computerized framework which meets the needs of different users, and which integrates in a flexible, coherent way all the functions of a simulation plan.

Building plan description where it is essential to develop a standardized way of representing a building plan. This is the goal of the mission of the Centre Scientifique et Technique du Bâtiment which has been given by the French Administration through the work of PROJIBAT (21). Shared in the future by all partners in the construction process, the description data base resulting from this task will link energy simulation systems and C.A.D. systems.

The generation of a model which translates this description into a global formulation deduced automatically from the Model Library (the "MODELOTHEQUE") and/or following instructions given by the user. It must be possible to complete the Model Library at the user's request to find different ways of representing a given component according to the degree of user's knowledge and to the degree of precision expected locally for this component. From the user's point of view, the mathematical form of these models must be as simple as possible in order to reduce to a minimum any re-writing, and also to help the user understand the model more easily. The kinds of formulations accepted are those frequently encountered in Applied Physics : RC networks, differential equations, state-space vector forms, discrete and continuous transfer functions. From the point of view of the simulation program, each component should share a common form which could be the state-space form.

The generation of a numerical environment, based on a Library of Solvers. The objective is to put the whole model in the numerical environment best adapted to the kind of problem posed. In addition to a detailed analysis of this model in the different regimes (steady, periodic or transient state), it must also be possible to find in this library the numerical techniques of identification and reduction of models. Finally, from the point of view of solving, several techniques of numerical integration must be proposed, in particular those based on variable time step methods and those based on hierarchical integration as a function of the time constants encountered.

Execution, which must take care of editing the links between the different machine codes.

The processing and publication of simulation results, in a language developed specifically to permit the user to present results in an appropriate form.

Finally, it should be noted that these development programs have been undertaken with an underlying desire to improve the flexibility and the portability of these simulation tools. They notably attempt to take advantage of the recent developments of computer sciences (programming languages, data base and code management systems).

6. Conclusion

Without in any way wanting to standardize the mathematical representation of physical phenomena (that is to say, not to standardize the models themselves), it is clear that the practical use of the body of knowledge built up around Building Energy Analysis would be considerably helped by the development of a common structure to improve access for users. This structure would be a common computerized framework which would encourage mutually-enriching contacts between the different Groups in the building sector, and in turn act as a stimulus for innovation.

The computer brings us new, powerful processing techniques, as much a consequence of advances in programming techniques as of developements in hardware. These advances will in turn facilitate more powerful and more manageable simulations.

Finally, when this perhaps ambitious project is put in place, it is not difficult to imagine how efficiently complex studies could be performed and also the distinct advantages of researchers and designers being able to exchange not FORTRAN programs but models in which the physical phenomena represented are clear.

Is this not the true place of the computer in Building Energy Analysis ?

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Formulation of Building Regulations using Interactive Logic Programs

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ABSTRACT

The Directorate is responsible for the Building Standards (Scotland) Regulations which set out statutory technical requirements for building design and construction. As a part of a major review programme the Directorate is developing the use of interactive logic-based programs to assist in the formulation, evaluation and drafting of revised Regulations. The Regulations are formalized as a set of rules and definitions in logic programs written in micro-PROLOG. Such programs have both a declarative and a procedural interpretation. Declaratively the program can be regarded as a specification of the required Regulation which can be progressively developed and refined in a top-down manner. The formalization clarifies the logical structure of the Regulation and helps to avoid syntactic or semantic ambiguities. Procedurally the formalization can be run as an interactive program and the logical consequences of applying a set of Regulation requirements in any context examined. A trace of the computation records the network of rules and definitions used to arrive at a given conclusion. The inherent modularity of logic programs allows changes and modifications to be easily introduced and their effects tested. Building Regulations developed and formalized as logic programs constitute a ready-made knowledge base for use in expert systems applications.