RECENT DEVELOPMENTS OF BUILDING ENERGY SIMULATION TOOLS IN EUROPE

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ABSTRACT - Without going into an exhaustive inventory of the European work on Building Energy Simulation Tools, we describe some state-of-the-art computer-based simulation programs which are specific to the European context. In addition, some validation tests and methodological approaches are discussed. However, while knowledge in building energy modelling has made considerable progress since 1960, access to this body of knowledge remains limited for both designers and researchers. We review the deficiencies and explain why they exist. We point out that different parties in the building sector have different needs in terms of building energy analysis tools. We describe the European participation in the international organization which has been set up to develop together a new generation of simulation tools. Finally, we present the French point of view which stresses the need for a common computerized framework to give users access to a calculation and data base.

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 calculation framework. The result has been the development of a wide range of computerized simulation tools, principally in North America, but also in Europe. At the end of 25 years of work, it is useful to pause and look closely at the programs which are currently available to researchers and designers in the field of energy analysis, and also to look at the kind of studies which could be carried out.

A complete and exhaustive inventory of all the studies which have been carried out at the European scale in the field of building energy simulation would not be easy, and would probably have the effect of drowning the reader in an ocean of details. For this reason, the author has chosen to present certain key aspects of the European context, knowing well that this body of work has many points in common with studies on other continents, in particular North America (1).

The specificities of the European work concern firstly, the computer products which are particular to the European situation : two computer-based simulation programs which represent the state-of-the-art in Europe are presented below : ASTEC and ESP ; the work carried out in the validation of programs and simplified methods ; but also the analytical approaches, both experimental and theoretical.

The end-users concerned by these thermal simulation projects constitute, in Europe, a group which has its own particular characteristics. They show, in 1985, very precise needs which will become evident in the course of this presentation. Two basic approaches can be identified : the global and the detailed. These two approaches have long been considered as opposed - the former considered as being "empirical" and the latter "theoretical". We want now to look at their respective methods and applications.

Demand for simulation tools is increasing as a direct consequence of the increasing adoption of computerized methods in the building sector, in particular of Computer Aided Design (C.A.D.). The supply side (the producers of computer-based programs for analysing thermal processes) has encountered problems in adapting to this new clientele. Quite often, the programs proposed have been too complicated to be used without considerable programming experience, and too limited in their field of application. One example is presented to illustrate these weaknesses, which can have serious consequences for certain studies.

Thus, there is an ever-increasing gap between the designers of computer-based simulations and the people using them (2). Several laboratories in Europe and the United States have decided to coordinate their work in order to develop a common framework of thermal simulation tools which could become operational by 1990. The international organization is introduced below, along with the European contribution. Finally, the French proposals for action to be taken are presented in the context of this international project.

2. EUROPEAN WORK ON BUILDING ENERGY SIMULATION TOOLS

Two building energy simulation tools as a reference in Europe

Rather than present a complete overview of the large number of simulation tools developed in ~ope for building energy analysis purposes, the .hor presents two simulation programs in detail. These programs are the state-of-the-art building energy analysis tools.

- ASTEC 3 as a general purpose simulation program ;
- ESP as a building energy simulation program.

ASTEC 3 - A general purpose simulation program

The thermal-electrical analogy has oriented many research groups in Europe towards the ASTEC general purpose simulation program. Aimed at treating electrical and electronic circuits, ASTEC can also simulate systems governed by differential algebraic equations. It was developed in France at the Commissariat à l'Energie Atomique (3) and it is now marketed in French and English by the Compagnie Internationale de Services en Informatique (C.I.S.I.)

ASTEC 3 has a strongly structured input language and offers great flexibility and high functionality for describing circuits and models through the following features :

. branch-by-branch description of circuits ;
. model definitions are available for user-defined model description, as well as sub-network descriptions which can be recalled in other model or circuit descriptions ;
odel descriptions can be given under the form of equivalent networks mixed with differential equations ;
. element and parameter values can be described as arithmetic expressions, conditional statements, tables and user-written FORTRAN functions ;
. availability of a library management system, which allows storing of any model or sub-network which is used in other designs ;
. availability of a thermal model library which offers state-of-the-art models for common building elements.

ASTEC consists essentially of a true optimizing compiler which produces for each circuit description an optimal executable machine code. This code is then loaded and executed during the simulation runs.

ASTEC is able to simulate linear or non-linear electrical circuits as well as systems of ordinary differential equations.It can be used to carry out transient, DC or AC steady-state simulations.

ASTEC is one of the most powerful circuit simulators available today. It has been used extensively since 1978 in France and in Europe by many companies, mainly in electronic applications, but also in hydraulic, pneumatic and biological applications. In the field of energy analysis, the thermic-electric analogy has been known for a long time and Centre Scientifique et Technique du Bâtiment in France has especially contributed in that way (4) thanks to the analog computer at its disposal. ASTEC has been used for a large number of applications such as : simulation of the dynamics of heat pumps (5), studies on unsteady states of district heating (6), environmental control of SPACELAB (7).

ESP - A building energy simulation program

ESP - Environmental Systems Performance - is a building/plant energy simulation system developed by the Abacus (Architecture and Building Aids Computer Unit) at the University of Strathclyde in England (8).

ESP is a transient energy simulation system capable of modelling the energy and mass flows within combined building and plant systems. Any building, defined as a collection of interlocking polyhedral zones (specified in terms of geometry, construction and usage profiles), can be associated with a plant system consisting of a distributed network of plant components. The combined system can then be subjected to simulation processing under dynamic control. ESP is as applicable to existing building as it is to proposed new designs incorporating traditional or advanced tecnological features. The system has been designed to operate in "interactive graphics" and "automatic processing" modes and has sophisticated input/output facilities to enable the designer to address such design questions as :

What will be the effect of some design change, such as increasing wall insulation, changing the glazing type or distribution, re-zoning the building, reconfiguring the plant system or changing the building/plant control schedules ?

This allows the designer to identify potential problem areas, appropriate building and plant modifications, energy saving operational strategies, comfort levels, condensation risks, etc ...

The central simulation "engine" of ESP predicts building and plant energy flows and building air flows by a rigorous first principle modelling technique. As the programs steps through small time increments, it continously subdivides the building/plant network into a number of finite volumes. By applying energy balance techniques, unconditionally stable equation structures are produced, which can be solved by special matrix processing software. The techniques used for equation formulation and solution are described in detail in reference (9).

Other studies

These two programs have been presented in detail, not because they are representative in terms of the number of simulations carried out, not because of their being used by a majority of research groups in Europe, but because they include features which are extremely interesting from the point of view of both calculating power and ease of use.

In addition, we have to mention other European works on :

Detailed calculation programs. Notably the LPB-1 (10) program of the Laboratoire de Physique de Liège in Belgium, the work on JULOTTA (11) program at the Royal and Lund Institute of Technology in Sweden, and CALECO/DOE-2 (12) at the

Centre National de la Recherche Scientifique and CSTBât (13) at the Centre Scientifique et Technique du Bâtiment in France.

Analytical approaches. In particular the work of the Ecole Nationale Supérieure des Mines de Paris which attempts to approach energy simulation from the angle of modal analysis (14). With their origins in control theory, these techniques (15) seek to reduce the size of models as much to give the global behaviour of the system as to permit simulation of complex systems. Furthermore, the Laboratoire d'Automatique in Grenoble has focussed interest on the identification of models from the results of detailed simulation or from experimental data. The knowledge gained has been put together in under the form of the SIRENA (16) computer-based simulation program.

Formalism of connections between models. The Université Paul Sabatier in Toulouse has been trying to solve this critical problem in the form of a "Formalisme d'Evolution des Transferts" (17), tested by the ZOOM program (18). In the same area, we must also refer to the introduction of the boundary element method (19) to energy analysis. This method, already frequently used in engineering appears to offer considerable gains in calculation time.

Validation tests

As far as the problem of validation of detailed simulation programs is concerned, we cannot overlook the work which has been done in the framework of the Annex 10 "System Simulation", under the leadership of the International Energy Agency (Energy Conservation in Buildings and Community System Program). Their main objective is to refine the calculation procedures for estimations of energy needs by taking heating and air-conditioning installations better into account. These studies, organized by the Laboratoire de Physique de Liège (Belgium) group several European countries : Finland, Germany, Italy, Sweden, Switzerland, the Netherlands and the United-Kingdom. The goal is to constitute a data base of HVAC component specifications. This data base is validated by simulation exercises and full-scale experimental data.

Using examples simplified to the extreme, the simulation exercises (20) have been compared with most of the heavy calculation programs currently available in the world. They show an average dispersion of the order of ± 20%. But since the comparisons have been made between the output results of the different programs, it is difficult to know whether these differences result from the working methods or the working hypotheses.As far as the comparisons calculation/measurement are concerned, differences of up to ± 50% have been noticed between the estimations of heating and cooling load. The inter-room air movements could in part account for these differences. But, fortunately, the comparisons which produce such large differences are relatively few in number and it is also possible to find cases which give excellent agreement between measured and calculated values. This is so in the case of the study carried out by the CNRS (21) using the CALECO/DOE-2 code, in the course of a retrofit project in Dreux (France).

It should be noted that, over long periods of analysis, other studies have revealed significant lack of fit between calculated/measured values of the heat-loss coefficient in steady state. This is the case notably in a building in Bourgoin-Jallieux (France) (22) which, in other climatic situations, matched the results of the CLIM simulation program developed by the Electricité de France (EdF).

It would be wrong to generalize too much from these kinds of comparisons, but it is possible to say that presently-available simulation tools, even when highly detailed, have a strong error component. It is not possible to say with any degree of assurance in exactly what respects they are wrong or misleading. This lack of knowledge prevents any possible intervention in the model, even if it is clear that certain mechanisms are badly represented for example, outdoor/indoor, internal or inter-room air movements, heat transfer through the ground, interactions between enclosure/controls/equipment, and also the behaviour of the occupants. It is, however, possible to ask if the interpretation of these differences would not be helped if the comparisons were carried out on the basic models rather than on the results of the calculation programs. The next generation of simulation tools envisaged in France (cf. chapter 6) should bring some improvement to this situation because the basic formulation of the model is accessible to the user, and also because the identification techniques allow recalibration of the parameters of certain models.

We notice also important divergences between the simplified design tools, notably in France where the national regulation context has led to the development of a number of methods specifically oriented towards professionals in the building sector. In the framework of the H2E85 program of the French Administration (Plan Construction et Habitat), a task was assigned to the Atelier d'Evaluation in 1984 to carry out a survey of all computer aided design tools and to produce a catalogue. A special study, supported by the Agence Française pour la Maîtrise de l'Energie, was also set up in this workshop, to bring together the working hypotheses and modelling techniques of all the research teams concerned.

In the more limited domain of the design of solar energy systems, the Modelling Sub-Group of the Commission of the European Community has also attempted to unify European computerized methods to provide a simplified and easy-to-use tool for design purposes in active solar heating and domestic hot water applications (23). The ESP computer program described above was chosen as a reference point for the validation of some fifteen methods.

Finally, on the validation of the models of certain physical phenomena, we can also refer to the French work of "l'Action de Recherche Concertée" ("co-ordinated research program"), titled : "Convection Naturelle dans l'Habitat" ("Natural convection in buildings") which attempts (24) to determine the convective heat transfer coefficients in the interior of a building shell, by both experimental and numerical means. The Laboratoire de Physique de Liège proposes (25) to replace the classical assumption of a isothermal space air by a two-zone model obtained by a graph reduction.

3. WHAT ARE THE PRESENT NEEDS IN ENERGY ANALYSIS TOOLS ?

Although thermal modelling of building has made considerable progress in the last 15 years (because of a better understanding of buildings, and thanks to computerized analysis), access to his body of knowledge is still limited for the different parties which compose the building sector.

A number of programs developed since 1975 have, however, made a significant contribution by offering powerful computer-based simulation tools. Mention should be made of NBSLD, DOE-2, TRNSYS, BLAST, ... in North America ; and ESP, CALECO/DOE-2 CSTBât, ASTEC, CLIM, LPB, ... in Europe.

Even though these computer programs were developed primarily for the professionals in the building sector, their use remains limited to relatively few consulting firms because they are difficult and complicated to use. As for the research community, the computing language in which the programs are created has proved to be a considerable constraint : any modification of the programs requires very large investments of time and energy for programming and numerical analysis in order to develop a new version of the programm -- often to the detriment of physical analysis of the phenomena concerned.

A critical review, summarized below, 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 (cf. chapter 6).

In terms of the computer-aided analysis which these "first generation" simulation programs have given, we can say that they have given researchers global estimations of energy efficiency, and have so contributed to a more accurate sizing of the components of buildings and of heating systems. There is, however, an increasing gap between the capacities and capabilities of simulation tools on the one hand, and the users needs on the other hand. At present (ignoring the obstacles directly associated with the difficulties of using the computer programs) we can identify 2 types of technical needs which remain partly or wholly unsatisfied.

<u>Need for a detailed simulation of building energy dynamics</u>

A building is a complex system which integrates, under given climatic conditions, components as varied as load-bearing walls, windows, interior walls, and equipment for producing or distributing heat. These components themselves are 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 approach to modelling the thermal dynamics of the overall system has generally been to try to integrate several more-or-less elaborate models of each of the individual sub-systems. This is clearly shown in the structure of existing programs.

This desire for developing highly detailed simulations is evident in a number of studies. The problem becomes extremely complex when interest is focussed on a detailed examination of the dynamics (linking the relationships between the occupants, the building envelope, various equipment, and the control/regulation system). In fact, it is very difficult for MODELS OF PHYSICAL PHENOMENA to take into account the kinds of transfers which become dominant when the time base for analysis is reduced (the problem of inter-related transfers).

On similar lines, we have noticed an increasing demand for DETAILED LOCALIZED ANALYSIS, which implies that it is necessary to put together models of different degrees of complexity. The PROCESS OF NUMERICAL RESOLUTION, which forms an integral part of the simulation programs, does not in general permit the co-existence of components having time constants which are markedly different (space air volume, thermostats, equipments, foundations, etc...).

<u>Need for a global analysis of a building system</u>

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 identify control laws.

Some programs attempt to show that it is possible to get around this obstacle by using powerful numerical integrators ; but this ignores the existence of controlled variables in a building. Such variables introduce a major constraint which must be taken into account if we really want to understand the dynamics of the envelope/equipment/regulation system. These variables are frequently ignored in existing simulation programs because they would necessitate a complete re-formulation of the problem in terms of the control theory.

It has been observed that the demand for global analysis is increasing -- a demand which is already found frequently in energy management of heating systems in buildings, but one for which the outstanding problems of identifying the parameters of simplified models and/or systems which are currently operating remain a serious obstacle to generating optimal economical control strategies and equipment. The following chapter points out, through an example, the lack of adequate tools for this kind of analysis.

Opening up the present codes to techniques of reduction and identification -- coming from control theory, whose use is 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 some models.

4. EXAMPLE OF SYSTEM ANALYSIS DEMAND : THE IRCOSE RESEARCH GROUP ACTIVITIES

A demand for a system analysis was made in 1983 when the French research group IRCOSE (Institut de Recherche sur la Commande Optimale des Systèmes Energétiques), led by the Agence Française pour la Maîtrise de l'Energie (AFME) and grouping the Centre Scientifique et Technique du Bâtiment (CSTB), the Ecole Nationale Supérieure des Mines de Paris (ENSMP), the Institut National de la Recherche en Informatique et Automatique (INRIA) and the Gaz de France (GDF)- attempted :

- to implement optimal control theory to minimize energy consumption costs while maximizing occupant thermal comfort in a twin-energy heating dwelling system, subject to dynamic constraints and under weather disturbances ;
- to assess efficiency by comparison with conventional controllers.

For the purpose of this study (26), a representative dwelling was selected. It is located in a typical multi-storey building and includes a basic heating floor with auxiliary electric convectors. Unfortunately, no building energy analysis computer code was able to give an appropriate support for this study and the researchers involved were obliged to develop their own tools at each step of the methodology. The latter is here reported in three steps to illustrate the deficiencies of existing simulation programs in applying control theory.

Developing a simplified dynamic model of the system

The dynamic model of the system (dwelling) should be sufficiently detailed to describe precisely the dynamics of the process, but not too complex to prevent a numerical solution to the optimization problem. So, the number of state variables was fixed - a priori - at two (the average envelope + air and average floor temperatures), and a second-order linear model was derived from the two energy balances developed for the envelope + air and on the heating floor of the dwelling.

A state-space formulation was selected to describe the simplified dynamic model essentially because the optimal control theory can be easily applied to this representation.

At this step, there was, on the one hand a simplified dynamic model with unknown parameters and, on the other hand the thermal process known either through on-site measurements or through a detailed model. For the application concerned, the actual process was not yet available, so the comparison was performed with a detailed model and the parameters were identified by minimizing the error with a least-squares algorithm.

Expressing the objective function

The model was then able to provide transient relationships between the input (energy consumption) and the output (thermal comfort) of the system. The next step was to attempt to express the objective function, that is, to minimize energy costs while maximizing comfort (in mathematical terms, a weighted combination of the energy cost and thermal discomfort).

Previous works on comfort (27) have shown that an elliptical zone could delimit the comfort area for the occupant. This zone, associated with a quadratic criteria,led to the definition of occupant comfort in terms of cost and the expression of a uadratic penalty function. After adding the energy costs, the overall cost function was obtained.

Applying the optimization procedure

The objective of the study could be described in the following terms : find the control scenario (heating power) on a finite slippery horizon which minimizes the objective function defined above, while satisfying the state-space equations. The mathematical optimization procedure used in this study was based on PONTRYAGIN's Minimum Principle which leads to define the Hamiltonian of the system. A gradient algorithm was used to solve at each time-step the minimization problem and to yield the commands to be applied to the heating system.

Conclusion : An application of the optimal control approach has been presented. Even if a quadratic criteria and a linearized low-order model was used, the methodology required the development of specific analysis tools at each step. This kind of analysis (called system analysis) is becoming more commonly used in building energy management. It shows the necessity of opening the present building energy analysis programs to other branches of knowledge besides thermal physics in order to promote the development of advanced technologies in the building field.

5. INTERNATIONAL PLAN FOR THE DEVELOPMENT OF THE NEXT B.E.A.P. GENERATION

Many European and American laboratories involved in the domain agree on the weaknesses of existing programs, and have taken steps to make a joint effort to co-operate in the development of new tools for building energy analysis which should be available by 1990. An international organization (under the name "ENERGY 1") was set up in 1984 on the initiative of Lawrence Berkeley Laboratory, with this as its objective. The international organization built up around ENERGY 1 has been operational since 1985, and is organized around four 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 :

LABORATORY	PROGRAMS DEVELOPED
RAMSES/CNRS Team (Orsay)	CALECO
UTI/FNB (Saint-Rémy les Chevreuse)	BILGO
CSTB (Sophia Antipolis, Valbonne)	CSTBât

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

. In Europe, several laboratories which are already active in the development of building energy analysis software now work in conjunction with ENERGY 1. 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 (NBS), who have worked closely with the Centre Scientifique et Technique du Bâtiment since 1977. Two organizations in the private sector have also been consulted : Honeywell who have a very sophisticated program called GEMS (Generalized Engineering Modelling and Simulation) and Johnston Controls, who have worked with the NBS to develop the HVACSIM+ program.

. We should also mention that China is associated with the project through the Chinese Academy of Sciences.

6. PROPOSAL BY THE FRENCH COMPONENT OF ENERGY 1

The GER ALMETH has taken an active part in the definition of computerized systems since the beginning of 1985, and stresses the need for ENERGY 1 to develop a common computerized framework to give users access to a calculation and data base. Practically speaking, the work carried out by the GER ALMETH has two components (28). The first is in the domain of physical analysis, and is aimed at making a synthesis of existing models of building thermal analysis. The objective is to group these existing models into a kind of "Model Library". 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 : Modelling of physical phenomena and numerical analysis

In contrast with what is happening in North America and at a much smaller scale in certain countries under the leadership of the International Energy Agency, France has previously made little investment in co-ordinated research projects to analyse, compare or test models of physical phenomena in building energy analysis. This is despite the fact that many studies have been carried out 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. The objective is to create a complete list of the large number of algorithms which have been developed. These algorithms are frequently buried inside complicated computer programs, and only the program writers really know how to have access to them. It is therefore essential to identify the basic formulation of the models ; this structure sets certain constraints on the numerical solutions -- constraints which must be clearly understood.

The main objective of this work is to build up a "Model Library". Each model is entered in the library in a file listing the hypotheses made, the domain of application of the model, and the experimental or numerical tests which have been carried t on it. The modelling experiments can be divided .tc 2 groups :

- the first group includes those which have few or no thermal inter-relations between the elements (shell elements, boiler, heat pump, ...) ;
- the second group includes all the inter-relations which exist between these sub-systems (radiant exchanges, natural convective transfers, inter-room air movements, envelope/equipment/regulation coupling, ...).

As for the criteria for selecting particular numerical approaches, the accent is placed on the need for compatibility of the different algorithms, especially in the delicate case of the inter-relationships between the building shell, the equipment and the regulation/control system which involve sub-systems with very different time constants. The problems of reduction and identification, necessary for carrying out a system analysis, are also examined.

Action Plan n°2 : Giving access to computer programs

First, we should look at the computer-based aspects of the common framework which will constitute the second part of the project.

An inventory of the different types of users (researchers, teachers, designers, builders, ...) helps us to identify specific kinds of demand for simulation tools, and demonstrates that one single program cannot satisfy such a diverse audience.

In the design field, for example, "Cost" and "Ease of Use" are key factors. In addition, a preference is shown for the ability to use a wide range of modelling components rather than for detailed local refinements. In the research field, on the other hand, detailed localized analysis of one part of the system is frequently a key feature. Thus, it will be necessary to modify, replace or complete certain models in the library, but without entering into a machine code. The era of models locked up in machine code and accessible only to programmers is over : it must now be possible for the user to set up his own model of a problem without having to learn a programming language first.

These examples demonstrate the need to build up a common computerized framework which meets the needs of different users, and which integrates in a flexible, coherent way the functions of a simulation :

building plan description. It is essential to develop a standardized way of representing a building plan. This is the mission of the Centre Scientifique et Technique du Bâtiment which has been given by the French Administration through the work of PROJIBAT. The objective is to standardize the description of a building plan for all partners in the construction process ;

the generation of a model which translates this description into a global formulation deduced automatically from the library of basic models (the Model Library, called the "Modelothèque" in France), or following instructions given by the user.

It must be possible to complete the Model Library at the user's request, to meet his specific needs, and also to find different ways of representing a given component according to :

- the degree and kind of knowledge that the user has about the phenomena. This knowledge is acquired either through the analysis of the phenomenon itself, or through experimental measurement (identification theory) ;
- 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, the precise nature of which remains to be defined ;

the generation of a numerical environment, based on a Library of Solvers. The objective is to put the model in the numerical environment best adapted to the kind of problem posed. In addition to a detailed analysis of the overall model in the different regimes (steady, periodic or transient state), it must also be possible to find in this base the numerical techniques of identification and reduction of models. Finally, from the point of view of resolution, 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 -- the goal being to improve the speed and accuracy of calculation ;

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 of the facilities currently available to the user. They also attempt to use to a maximum new programming techniques currently available from software engineering.

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 developments 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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